CHAPTER 6

FIBER OPTICS AND LIGHTING SYSTEMS

INTRODUCTION

This chapter will expand on the information you learned in the CE Basic TRAMAN on fiber optics and area lighting and also introduce you to airfield lighting systems.

FIBER OPTICS

The CE Basic TRAMAN taught you that a fiber-optic data link had three basic functions:

- To convert an electrical input signal to an optical signal
- To send the optical signal over an optical fiber
- To convert the optical signal back to an electrical signal

The fiber-optic data link converts an **electrical signal** into an **optical signal,** permitting the transfer of data along an optical fiber. The fiber-optic device responsible for that signal conversion is a fiber-optic transmitter.A **fiber-optic transmitter** is a hybrid device. The transmitter converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber-optic transmitter consists of an **interface circuit,** a **source drive circuit,** and an **optical source.**

The **interface circuit** accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The **source drive circuit** intensity modulates the optical source by varying the current through the source. An optical source converts electrical energy (current) into optical energy (light). Light emitted by an **optical source** is launched, or coupled, into an optical fiber for transmission.

Fiber-optic data link performance depends on the amount of optical power (light) launched into the optical fiber. This chapter provides an overview of optical sources and fiber optic transmitters.

OPTICAL SOURCE PROPERTIES

The development of efficient semiconductor optical sources, along with low-loss optical fibers, has led to substantial improvements in fiber-optic communications. Semiconductor optical sources have the physical characteristics and performance properties necessary for successful implementations of fiber-optic systems. Optical sources should do the following:

- Be compatible in size to low-loss optical fibers by having a small light-emitting area capable of launching light into fiber.
- Launch sufficient optical power into the optical fiber to overcome fiber attenuation and connection losses, allowing for signal detection at the receiver.
- Emit light at wavelengths that minimize optical fiber loss and dispersion. Optical sources should have a narrow spectral width to minimize dispersion.
- Allow for direct modulation of optical output power.
- Maintain stable operation in changing environmental conditions (such as temperature).
- Cost less and be more reliable than electrical devices, thereby permitting fiber-optic communication systems to compete with conventional systems.

Semiconductor optical sources suitable for fiber-optic systems range from inexpensive light-emitting diodes (LEDs) to more expensive semiconductor lasers. Semiconductor LEDs and laser diodes (LDs) are the principal light sources used in fiber optics.

SEMICONDUCTOR LIGHT-EMITTING DIODES AND LASER DIODES

Semiconductor LEDs emit **incoherent light.** Spontaneous emission of light in semiconductor LEDs produces light waves that lack a fixed-phase relationship. Light waves that lack a fixed-phase relationship are referred to as **incoherent light.** LEDs are the preferred optical source for multimode systems because they can launch sufficient power at a lower cost than semiconductor laser diodes (LDs).

Semiconductor LDs emit **coherent light.** Light waves having a fixed-phase relationship are referred to as coherent light. Since semiconductor LDs emit more focused light than LEDs, they are able to launch optical power into both single mode and multimode optical fibers; however. LDs usually are used only in single mode fiber systems because they require more complex driver circuitry and cost more than LEDs.

Optical power produced by optical sources can range from microwatts (μW) for LEDs to tens of milliwatts (μW) for semiconductor LDs; however, it is not possible to couple all the available optical power effectively into the optical fiber for transmission.

The amount of optical power coupled into the fiber is the relevant optical power. It depends on the following factors:

- The angles over which the light is emitted
- The size of the light-emitting area of the source relative to the fiber core size
- The alignment of the source and fiber
- The coupling characteristics of the fiber

Typically, semiconductor lasers emit light spread out over an angle of 10 to 15 degrees. Semiconductor LEDs emit light spread out at even larger angles. Coupling losses of several decibels (dB) can easily occur when coupling light from an optical source to a fiber, especially with LEDs.

SEMICONDUCTOR MATERIAL

Understanding optical emission in semiconductor lasers and LEDs requires knowledge of semiconductor material and device properties. Providing a complete description of semiconductor properties is beyond the scope of this text. In this chapter we will only discuss the general properties of semiconductor LEDs and LDs.

Semiconductor sources are diodes, with all of the characteristics typical of diodes; however, their construction includes a special layer, called the active layer, that emits photons (light particles) when a current passes through the layer. The particular properties of the semiconductor are determined by the materials used and the layering of the materials within the semiconductor. **Silicon (Si)** and **gallium arsenide (GaAs)** are the two most common semiconductor materials used in electronic and electro-optic devices. In some cases, other elements, such as aluminum (Al), indium (In), and phosphorus (P), are added to the base semiconductor material to modify the semiconductor properties. These elements are called dopants. Current flowing through a semiconductor optical source causes it to produce light.

LEDs generally produce light through **spontaneous emission** when a current is passed through them. Spontaneous emission is the random generation of photons within the active layer of the LED. The emitted photons move in random directions. Only a certain percentage of the photons exit the semiconductor and are coupled into the fiber. Many of the photons are absorbed by the LED materials and the energy is dissipated as heat. This process causes the light output from a LED to be incoherent, have a broad spectral width. and have a wide output pattern.

Laser diodes are much more complex than LEDs. **Laser** is an acronym for **Light Amplification by the Stimulated Emission of Radiation.** Laser diodes produce light through stimulated emission when a current is passed through them. **Stimulated emission** describes how light is produced in any type of laser. In the laser diode, photons, initially produced by, spontaneous emission, interact with the laser material to produce additional photons. This process occurs within the active area of the diode called the laser cavity.

As with the LED, not all of the photons produced are emitted from the laser diode. Some of the photons are absorbed and the energy dissipated as heat. The emission process and the physical characteristics of the diode cause the light output to be coherent, have a narrow spectral width. and have a narrow output pattern.

It is important to note that in both LED and laser diodes all of the electrical energy is not converted into optical energy. A substantial portion is converted to heat. Different LED and laser diode structures convert different amounts of electrical energy into optical energy.

FIBER-OPTIC TRANSMITTERS

As stated previously, a fiber-optic transmitter is a hybrid electro-optic device. It converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber-optic transmitter consists of an interface circuit, a source drive circuit, and an optical source. The interface circuit accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The source drive circuit intensity modulates the optical source by varying the current through it. The optical signal is coupled into an optical fiber through the transmitter output interface.

Although semiconductor LEDs and LDs have many similarities. unique transmitter designs result from differences between LED and LD sources. Transmitter designs compensate for differences in optical output power, response time, linearity, and thermal behavior between LEDs and LDs to ensure proper system operation. Fiber-optic transmitters using LDs require more complex circuitry than transmitters using LEDs.

Transmitter output interfaces generally fall into two categories: optical connectors and optical fiber pigtails (fig. 6-1). **Optical pigtails** are attached to the transmitter optical source. This pigtail is generally routed out of the transmitter package as a coated fiber in a loose buffer tube or a single fiber cable. The pigtail is either soldered or epoxied to the transmitter package to provide fiber strain relief. The buffer tube or single fiber cable also is attached to the transmitter package to provide additional strain relief.

The transmitter output interface may consist of a **fiber-optical connector.** The optical source may couple to the output optical connector through an intermediate optical fiber. One end of the optical fiber is attached to the source. The other end terminates in

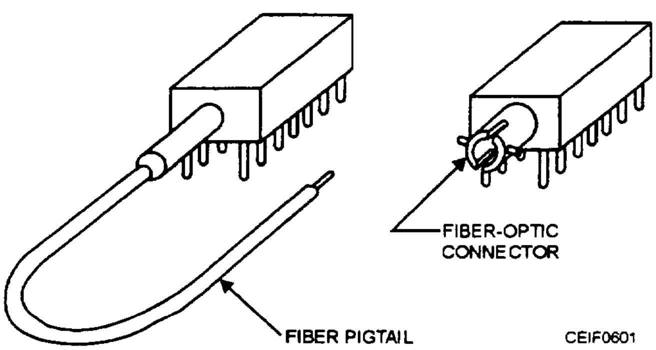


Figure 6-1.—Pigtailed and connectorized fiber-optic devices.

the transmitter optical output connector. The optical source also may couple to the output optical connector without an intermediate optical fiber. The optical source is placed within the transmitter package to launch power directly into the fiber of the mating optical connector. In some cases, **lenses** are used to more efficiently couple light from the source into the mating optical connector.

OPTICAL DETECTORS AND FIBER-OPTIC RECEIVERS

A fiber-optic transmitter is an electro-optic device capable of accepting electrical signals, converting them into optical signals, and launching the optical signals into an optical fiber. The optical signals propagating in the fiber become weakened and distorted because of scattering, absorption, and dispersion. The fiber-optic device responsible for converting the weakened and distorted optical signal back to an electrical signal is a fiber-optic receiver.

A **fiber-optic receiver** is an electro-optic device that accepts optical signals from an optical fiber and converts them into electrical signals. A typical fiber-optic receiver consists of an optical detector, a low-noise amplifier, and other circuitry used to produce the output electrical signal (fig. 6-2). The optical detector converts the incoming optical signal into an electrical signal. The amplifier then amplifies the electrical signal to a level suitable for further signal processing. The type of other circuitry contained within the receiver depends on what type of modulation is used and the receiver's electrical output requirements.

A transducer is a device that converts input energy of one form into output energy of another. An **optical detector** is a transducer that converts an optical signal into an electrical signal. It does this by generating an electrical current proportional to the

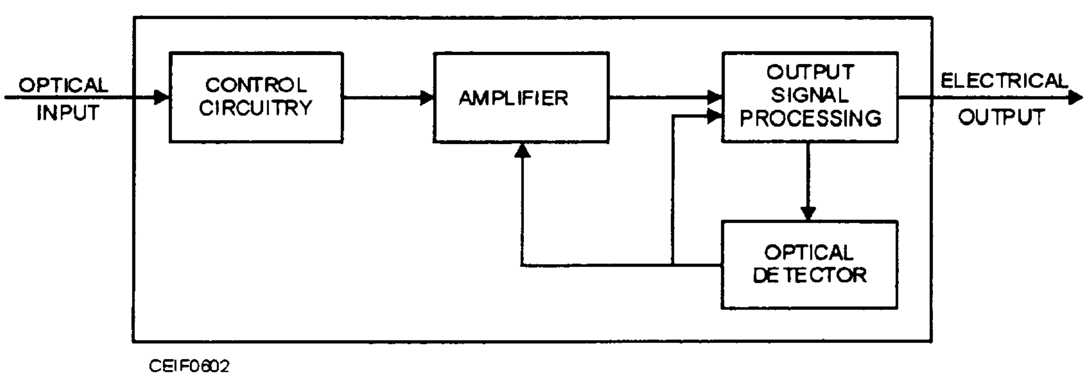


Figure 6-2.—Block diagram of a typical fiber-optic receiver.

intensity of incident optical radiation. The relationship between the input optical radiation and the output electrical current is given by the detector responsivity.

FIBER-OPTIC SYSTEM TOPOLOGY

Most of the discussion on fiber-optic data links provided earlier in this chapter and in the CE Basic TRAMAN refers to simple point-to-point links. A **point-to-point** fiber-optic data link consists of an optical transmitter, an optical fiber, and an optical receiver. In addition. any splices or connectors used to join individual optical fiber sections to each other and to the transmitter and the receiver are included. Figure 6-3 provides a schematic diagram of a point-to-point fiber-optic data link.

A common fiber-optic application is the full duplex link. This link consists of two simple point-to-point links. The links transmit in opposite directions between the equipment. This application may be configured using only one fiber. If configured with one fiber. fiber-optic splitters are used at each end to couple the transmit signal onto the fiber and receive signals to the detector.

All fiber-optic systems are simply sets of point-to-point fiber-optic links. Different system topologies arise from the different ways that point-to-point fiber-optic links can be connected between equipment. The term **topology,** as used here, refers to the configuration of various types of equipment and the fiber--optic components interconnecting them. This equipment may be computers, workstations, consoles, or other equipment. Point-to-point links are connected to produce systems with linear bus, ring, star, or tree topologies. Point-to-point fiber-optic links are the basic building block of all fiber-optic systems.

SYSTEM INSTALLATION

The Navy has a standard to provide detailed information and guidance to personnel concerned with the installation of fiber-optic cables and cable plants. The **fiber-optic cable plant** consists of all the fiber-optic cables and the fiber-optic interconnection equipment, including connectors, splices, and interconnection boxes. The fiber-optic cable and cable plant installation standard consists of the following:

- Detailed methods for cable storage and handling, end sealing, repair, and splicing
- Detailed methods for fiber-optic equipment installation and cable entrance to equipment
- Detailed methods to install fiber-optic cables in cableways
- Detailed methods for installing fiber-optic connectors and other interconnections, such as splices
- Detailed methods for testing fiber-optic cable plants before, during, and after installation and repair

There are other standards that discuss fiber-optic system installation. Many of these standards incorporate procedures for repair, maintenance, and testing. The techniques developed for installing fiber-optic hardware are not much different than for installing hardware for copper-based systems: however. the primary precautions that need to be emphasized when installing fiber-optic systems are as follows:

- Optical fibers or cables should never be bent at a radius of curvature less than a certain value, called the **minimum bend radius.** Bending an optical fiber or cable at a radius smaller than the minimum bend radius causes signal loss.

- Fiber-optic cables should never be pulled tight or fastened over or through sharp comers or cutting edges. Extremely sharp bends increase the fiber loss and may lead to fiber breakage.

- Fiber-optic connectors should always be cleaned before mating. Dirt in a fiber-optic connection will significantly increase the connection loss and may damage the connector.

- Precautions must be taken so the cable does not become kinked or crushed during installation of the

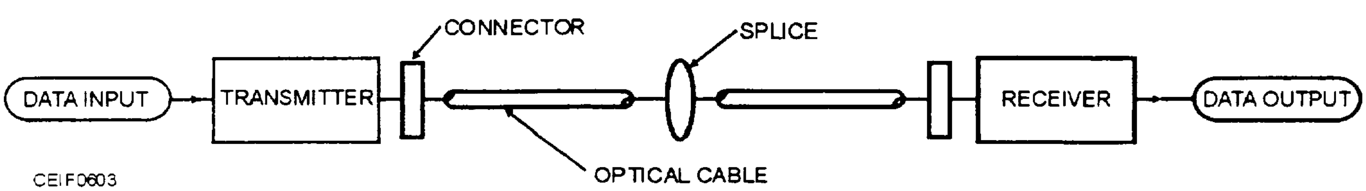


Figure 6-3.—A schematic diagram of a point-to-point fiber-optic data link.

hardware. Extremely sharp kinks or bends increase the fiber loss and may lead to fiber breakage.

FIBER-OPTIC MEASUREMENTS

Fiber-optic data links operate reliably if fiber-optic component manufacturers and you perform the necessary laboratory and field measurements. Manufacturers must test how component designs, material properties, and fabrication techniques affect the performance of fiber-optic components. These tests can be categorized as design tests or quality control tests. Design tests are conducted during the development of a component. Design tests characterize the performance of the component (optical, mechanical, and environmental) in the intended application. Once the performance of the component is characterized, the manufacturer generally only conducts quality control tests. Quality control tests verify that the parts produced are the same as the parts the design tests were conducted on. When manufacturers ship fiber-optic components, they provide quality control data detailing the results of measurements performed during or after fabrication of the component.

You, as the installer, should measure some of these parameters upon receipt before installing the component into the fiber-optic data link. These tests determine if the component has been damaged in the shipping process. In addition, you should measure some component parameters after installing or repairing fiber-optic components in the field. The values obtained can be compared to the system installation specifications. These measurements determine if the installation or repair process has degraded performance of the component and will affect data link operation.

FIELD MEASUREMENTS

Field measurements measure the transmission properties of installed fiber-optic components. You must perform field measurements to evaluate those properties most likely affected by the installation or repair of fiber-optic components or systems.

The discussion on field measurements is limited to optical fiber and optical connection properties. Optical fiber and optical connection field measurements evaluate only the transmission properties affected by component or system installation or repair. Because optical fiber geometrical properties, such as core and cladding diameter and numerical aperture, are not expected to change, there is no need to remeasure these properties. The optical connection properties that are likely to change are connection insertion loss and reflectance and return loss.

Field measurements require rugged, portable test equipment, unlike the sophisticated test equipment used in the laboratory. Field test equipment must provide accurate measurements in extreme environmental conditions. Since electrical power sources may not always be available in the field, test equipment should allow battery operation. In addition, while both fiber ends are available for conducting laboratory measurements, only one fiber end may be readily available for field measurements. Even if both fiber ends are available for field measurements, the fiber ends are normally located some distance apart, thereby requiring two people to perform the measurements.

The main field measurement technique involves optical time domain reflectometry. An **optical time domain reflectometer (OTDR)** is recommended for conducting field measurements on installed optical fibers or links of 50 meters or more in length. An OTDR requires access to only one fiber end. An OTDR measures the attenuation of installed optical fibers as a function of length. It also identifies and evaluates optical connection losses along a cable link and locates any fiber breaks or faults.

Users also can measure fiber attenuation and cable plant transmission loss, using an optical power meter and a stabilized light source. Use this measurement technique when optical time domain reflectometry is not recommended. Measurements obtained with a stabilized light source and power meter are more accurate than those obtained with an OTDR. Measuring fiber attenuation and transmission loss using a power meter and light source requires access to both ends of the fiber or link. An **optical loss test set (OLTS)** combines the power meter and source functions into one physical unit.

OPTICAL TIME DOMAIN REFLECTOMETRY

You use optical time domain reflectometry to characterize optical fiber and optical connection properties in the field. In optical time domain reflectometry, an OTDR transmits an optical pulse through an installed optical fiber. The OTDR measures the fraction of light that is reflected back. When you compare the amount of light scattered back at different times, the OTDR can determine fiber and connection losses, When several fibers are connected to form an installed cable plant, the OTDR can characterize optical fiber and optical connection properties along the entire length of the cable plant. A **fiber-optic cable plant** consists of optical fiber cables, connectors, splices, mounting panels, jumper cables, and other passive components. A cable plant does not include active components, such as optical transmitters or receivers.

The OTDR displays the backscattered and reflected optical signal as a function of length. The OTDR plots half the power in decibels (dB) versus half the distance. Plotting half the power in dB and half the distance corrects for round-trip effects. By analyzing the OTDR plot, or trace, you can measure fiber attenuation and transmission loss between any two points along the cable plant. You also can measure insertion loss and reflectance of any optical connection. In addition, you use the OTDR trace to locate fiber breaks or faults. Figure 6-4 shows an example OTDR trace of an installed cable plant.

MECHANICAL AND FUSION SPLICES

Mechanical splicing involves using mechanical fixtures to align and connect optical fibers. Mechanical splicing methods may involve either passive or active core alignment. Active core alignment produces a lower loss splice than passive alignment; however, passive core alignment methods can produce mechanical splices with acceptable loss measurements even with single mode fibers.

In the strictest sense, a mechanical splice is a permanent connection made between two optical fibers. Mechanical splices hold the two optical fibers in alignment for an indefinite period of time without movement. The amount of splice loss is stable over time and unaffected by changes in environmental or mechanical conditions.

The types of mechanical splices that exist for mechanical splicing include glass, plastic, metal, and ceramic tubes; also included are V-groove, and rotary devices: Materials that assist mechanical splices in splicing fibers include transparent adhesives and index matching gels. **Transparent adhesives** are epoxy resins that seal mechanical splices and provide index matching between the connected fibers.

GLASS OR CERAMIC ALIGNMENT TUBE SPLICES

Mechanical splicing may involve the use of a glass or ceramic alignment tube or capillary. The inner diameter of this glass or ceramic tube is only slightly larger than the outer diameter of the fiber. A transparent adhesive, injected into the tube, bonds the two fibers together. The adhesive also provides index matching between the optical fibers. Figure 6-5 illustrates fiber alignment using a glass or ceramic tube. This splicing technique relies on the inner

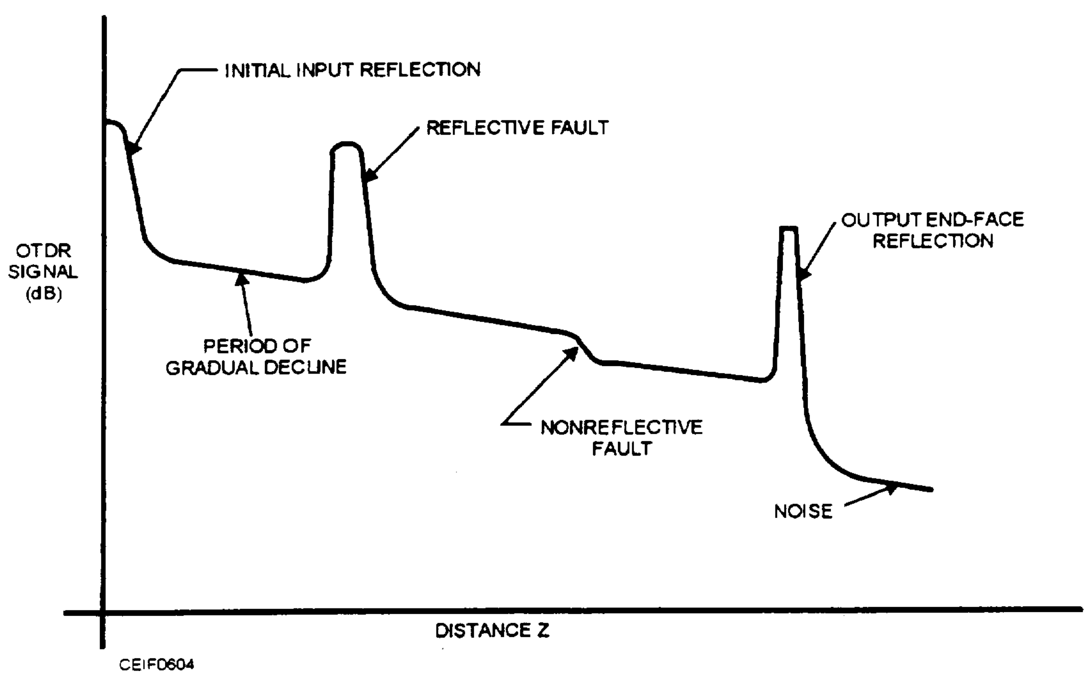


Figure 6-4.—OTDR trace of an installed cable plant.

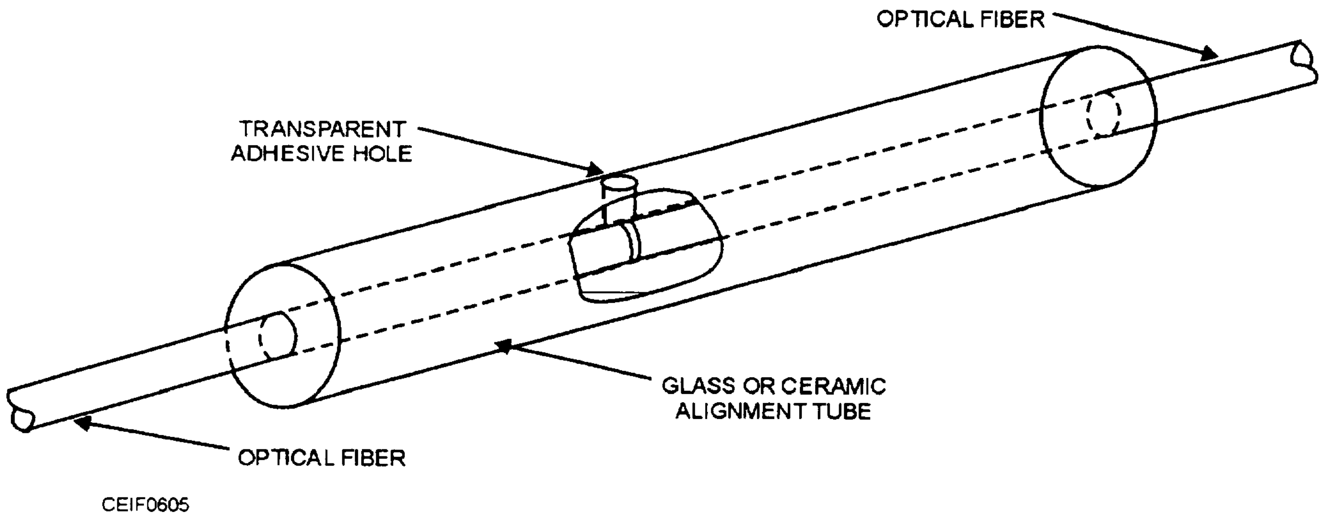


Figure 6-5.—A glass or ceramic alignment tube for mechanical splicing.

diameter of the alignment tube. If the inner diameter is too large, splice loss will increase because of fiber misalignment. If the inner diameter is too small, it is impossible to insert the fiber into the tube.

V-GROOVED SPLICES

Mechanical splices also may use either a grooved substrate or positioning rods to form suitable V-grooves for mechanical splicing. The basic V-grooved device relies on an open-grooved substrate to perform fiber alignment. When you are inserting the fibers into the grooved substrate, the V-groove aligns the cladding surface of each fiber end. A transparent adhesive makes the splice permanent by securing the fiber ends to the grooved substrate. Figure 6-6 illustrates this type of open V-grooved splice.

V-grooved splices may involve sandwiching the butted ends of two prepared fibers between a V-grooved substrate and a flat, glass plate. Additional V-grooved devices use two or three positioning rods to form a suitable V-groove for splicing. The V-grooved device that uses two positioning rods is the spring V-grooved splice. This splice uses a groove formed by two rods positioned in a bracket to align the fiber ends. The diameter of the positioning rods permits the outer surface of each fiber end to extend above the groove formed by the rods. A flat spring presses the fiber ends into the groove maintaining fiber alignment. Transparent adhesive completes the assembly process by bonding the fiber ends and providing index matching. Figure 6-7 is an illustration of the spring V-grooved splice. A variation of this splice

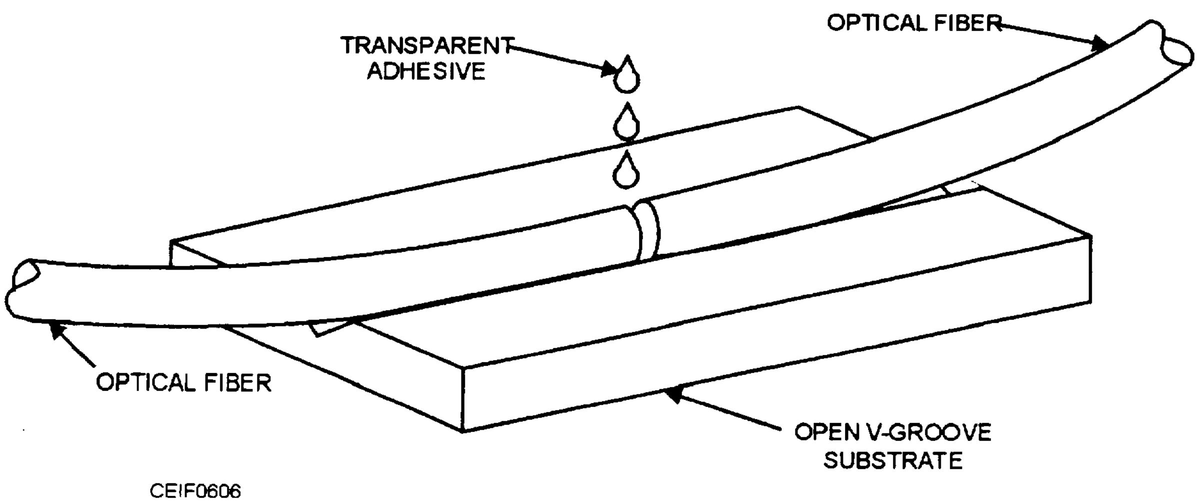


Figure 6-6.—Open V-grooved splice.

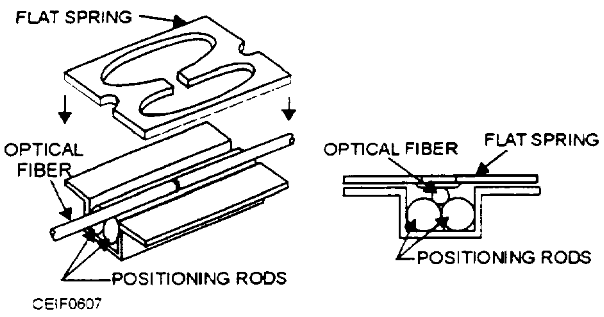


Figure 6-7.—Spring V-grooved mechanical splice.

uses a third positioning rod instead of a flat spring. The rods are held in place by a heat-shrinkable band or tube.

ROTARY SPLICES

In a rotary splice, the fibers are mounted into a glass ferrule and secured with adhesives. The splice begins as one long, glass ferrule that is broken in half during the assembly process. A fiber is inserted into each half of the tube and epoxied in place, using an ultraviolet cure epoxy. The end face of the tubes is then polished and placed together, using the alignment sleeve. Figure 6-8 is an illustration of a rotary mechanical splice. The fiber ends retain their original orientation and have added mechanical stability since each fiber is mounted into a glass ferrule and alignment sleeve. The rotary splice may use index matching gel within the alignment sleeve to produce low-loss splices.

FUSION SPLICES

The process of fusion splicing involves using localized heat to melt or fuse the ends of two optical fibers together. The splicing process begins by preparing each fiber end for fusion. Fusion splicing requires that all protective coatings be removed from the ends of each fiber. The fiber is then cleaved, using the score-and-break method. The quality of each fiber end is inspected with a microscope. In fusion splicing, splice loss is a direct function of the angles and quality of the two fiber end faces.

The basic fusion-splicing apparatus consists of two fixtures on which the fibers are mounted and two electrodes. Figure 6-9 shows a basic fusion-splicing apparatus. An inspection microscope assists in the placement of the prepared fiber ends into a fusion-splicing apparatus. The fibers are placed into the apparatus, aligned, and then fused together. Initially, fusion splicing used nichrome wire as the heating element to melt or fuse fibers together. New fusion-splicing techniques have replaced the nichrome wire with carbon dioxide (CO_2) lasers, electric arcs, or gas flames to heat the fiber ends, causing them to fuse together. The small size of the fusion splice and the development of automated fusion-splicing machines have made **electric arc fusion** (arc fusion) one of the most popular splicing techniques.

MULTIFIBER SPLICES

Normally, multifiber splices are only installed on ribbon type of fiber-optic cables. Multifiber splicing techniques can use arc fusion to restore connection, but most splicing techniques use mechanical splicing methods. The most common mechanical splice is the ribbon splice.

A ribbon splice uses an etched silicon chip, or grooved substrate, to splice the multiple fibers within a flat ribbon. The spacing between the etched grooves of the silicon chip is equal to the spacing between the fibers in the flat ribbon. Before you place each ribbon on the etched silicon chip, each fiber within the ribbon cable is cleaved. All of the fibers are placed into the grooves and held in place with a flat cover. Typically, an index matching gel is used to reduce the splice loss. Figure 6-10 shows the placement of the fiber ribbon on the etched silicon chip.

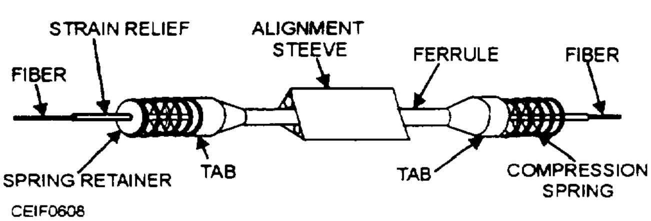


Figure 6-8.—Rotary mechanical splice.

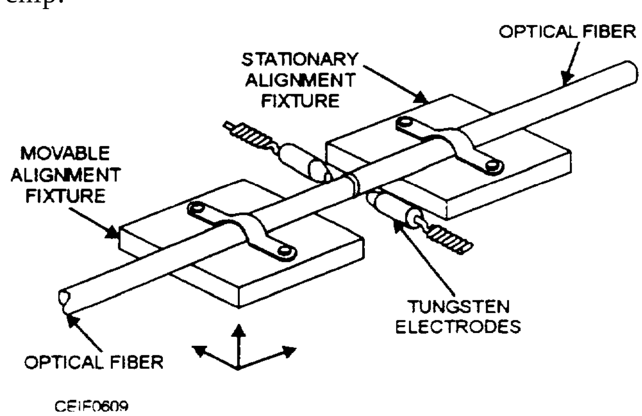


Figure 6-9.—A basic fusion-splicing apparatus.

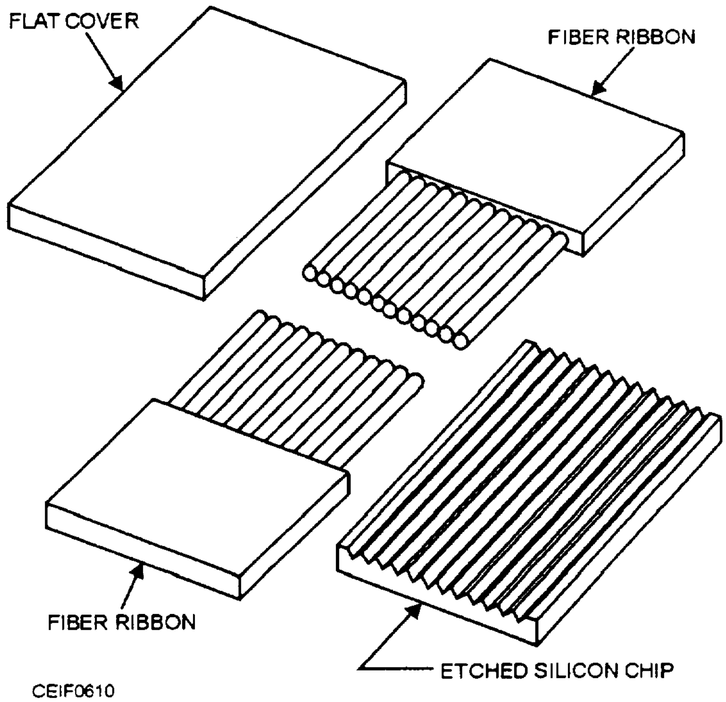


Figure 6-10.—Ribbon splice on etched silicon chip.

AREA LIGHTING SYSTEMS

Streetlighting at naval facilities usually need not produce as high a level of illumination as that required in many municipal areas. Because night activity by vehicles and pedestrians is low, only enough light is supplied to permit personnel to identify streets and buildings and to furnish sufficient visibility for local security requirements. Requirements for security and floodlighting systems will depend on the situation and the areas to be protected or illuminated.

STREET AND AREA CLASSIFICATION

Streetlighting requirements generally consist of a minimum average maintained footcandle level and a maximum allowable uniformity ratio for the installation. The authority for these requirements is the American National Standards Institute (ANSI)/Illuminating Engineering Society (IES) publication, *Standard Practice for Roadway Lighting.* Another publication that may prove helpful is *Informational Guide for Roadway Lighting,* published by the American Association of State Highway and Transportation Officials. The only significant difference between the two publications is that the latter allows a 4 to 1 uniformity ratio instead of the 3 to 1 uniformity ratio specified by IES. These uniformity ratios are defined as the ratio of the average footcandle value divided by the minimum footcandle value.

LIGHTING INTENSITY

The illumination and uniformity requirements are given in table 6-1. Note that the illumination level is dependent upon the roadway classification and the area classification that are defined in the following material.

Streets are classified into three major categories: major, collector, and local.

- Major: The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

- Collector: Distributor and collector roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas

- Local: Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic.

The locality or area is also defined by three major categories: commercial, intermediate, and residential.

- Commercial: That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high

Table 6-1.—Roadway Illumination and Lamp Selection Guide.

Area Class	Roadways Classification	Min. Average. Maint. FC	Uniformity Avg./Min. FC/FC
Residential	Local	0.4	6:l
	Collector	0.6	3:l
	Major	1.0	3:1
Intermediate	Local	0.6	3:l
	Collector	0.9	3:l
	Major	1.4	3:l
Commercial	Collector	1.2	3:l
	Major	2.0	3:l

pedestrian volume and a continuously heavy demand for off-street parking during business hours.

- Intermediate: That portion of a municipality which is outside of a downtown area but generally within the zone of influence of a business or industrial development; characterized often by a moderately heavy nighttime pedestrian traffic and a somewhat lower parking turnover than is found in a commercial area. This definition includes military installations, hospitals, and neighborhood recreational centers.

- Residential: A residential development, or a mixture of residential and commercial establishments, characterized by few pedestrians and a lower parking demand or turnover at night. This definition includes areas with single-family homes and apartments.

SELECTION OF LUMINAIRES

Luminaries are designed to provide lighting to fit many conditions. For street and area lighting, five basic patterns are available, as shown in figure 6-11. While many luminaries can be adjusted to produce more than one pattern, no luminaire is suitable for all patterns. Care must be used, especially in repair and replacement, to install the proper luminaire for the desired pattern, as specified in the manufacturer's literature. Even when the proper luminaire is installed, care must be used to ensure that all adjustments have been properly made to produce the desired results.

- Type I (fig. 6-11a) is intended for narrow roadways with a width about equal to lamp-mounting height. The lamp should be near the center of the street. A variation of this positioning (fig. 6-11b) is suitable for intersections of two such roadways with the lamp at the approximate center.

- Type II (fig. 6-11c) produces more spread than does Type I. It is intended for roadways with a width of about 1.6 times the lamp-mounting height with the lamp located near one side. A variation (fig. 6-11d) is suitable for intersections of two such roadways with the lamp not near the center of the intersection.

- Type III (fig. 6-11e) is intended for luminaries located near the side of the roadway with a width of not over 2.7 times the mounting height.

- Type IV (fig. 6-11f) is intended for side-of-road mounting on a roadway with a width of up to 3.7 times the mounting height.

- Type V (fig. 6-11g) has circular distribution and is suitable for area lighting and wide roadway intersections. Types III and IV can be staggered on opposite sides of the roadway for better uniformity in lighting level or for use on wider roadways.

MOUNTING HEIGHT AND SPACING

There are two standards for determining a preferred luminaire mounting height: the desirability of minimizing direct glare from the luminaire and the need for a reasonably uniform distribution of illumination on the street surface. The higher the luminaire is mounted, the farther it is above the normal

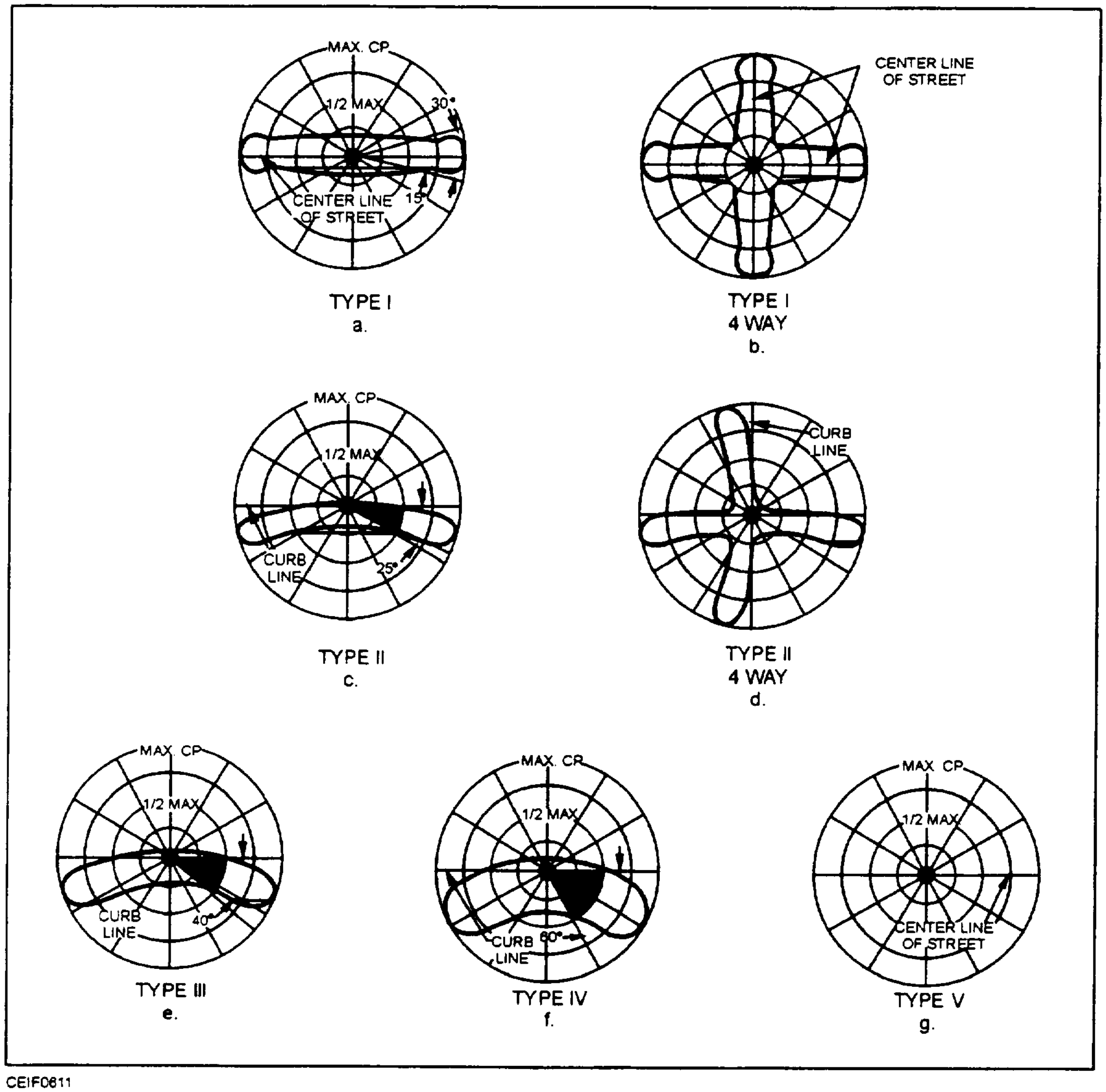


Figure 6-11.—Light distribution patterns for roadway lighting.

line of vision and the less glare it creates. Greater mounting heights may often be preferable, but heights less than 20 feet cannot be considered good practice.

You must be somewhat familiar with the terminology relating to how fixtures are located down a roadway. Figure 6-12 shows these relationships graphically. The following information will be useful when determining the most appropriate mounting arrangements:

- The “transverse direction” is defined as back and forth across the width of the road, and the “longitudinal direction” is defined as up and down the length of the road.

- Modern roadway fixtures are designed to be mounted in the vicinity of one of the curbs of the road. The “overhang” is defined as the dimension between the curb behind the fixture and a point directly beneath the fixture.

- A luminaire overhang should not exceed 25 percent of the mounting height.

- No attempt should be made to light a roadway that is more than twice the width of the fixture-mounting height. A roadway luminaire produces a beam in both longitudinal directions and is limited in its ability to light across the street.

- There are three ways that a luminaire may be positioned longitudinally down the roadway (fig. 6-12). Note that the spacing is always the dimension from one fixture to the next down the street regardless of which side of the street the fixture is located.

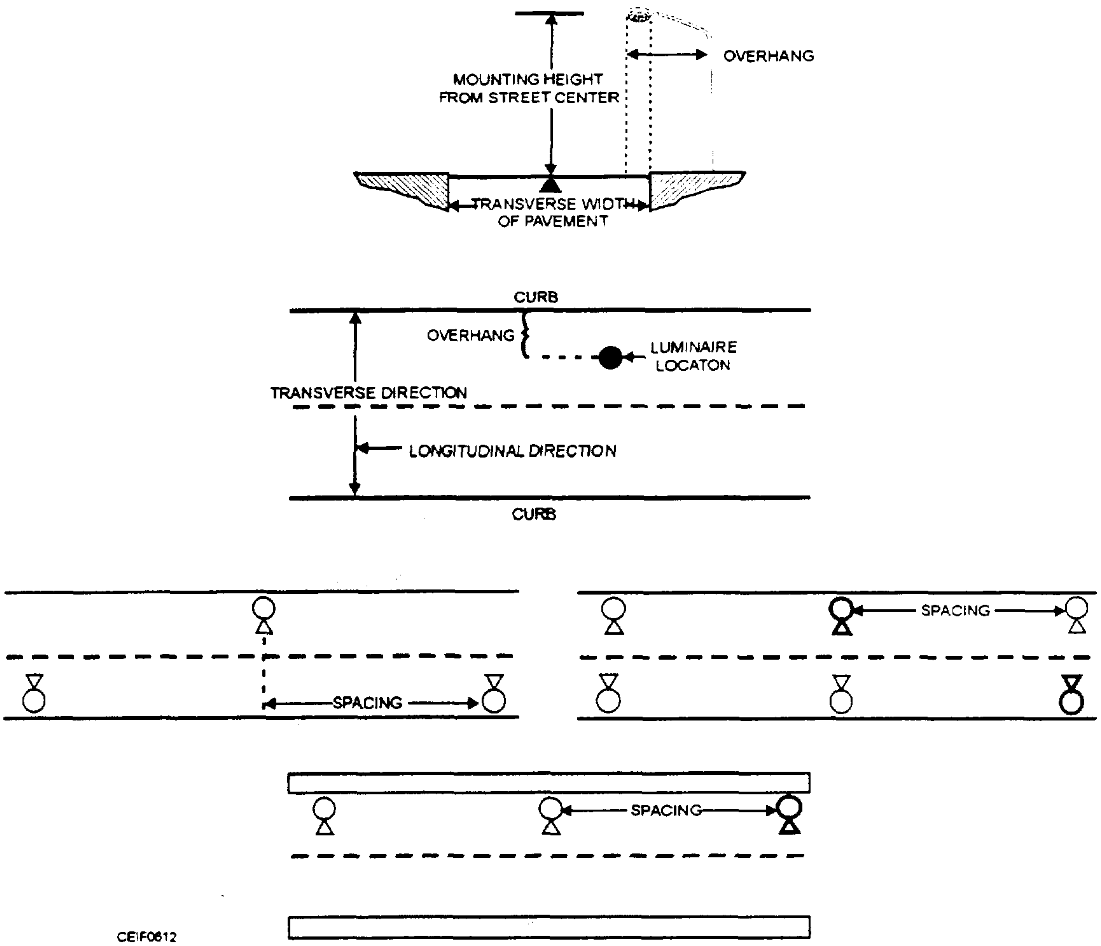


Figure 6-12.—Luminaire arrangement and spacing.

- A staggered arrangement generates better uniformity and possibly greater spacing than a one-side arrangement. That is particularly true when the width of the road becomes significantly greater than the mounting height. When the width of the road starts approaching two mounting heights, an opposite arrangement definitely should be considered. That would, in effect, extend the two-mounting-height width limitation out to four-mounting heights.

The classification of a road and the corresponding illumination levels desired influences the spacing between luminaries. On a residential road, it may be permissible to extend the spacing so that the light beams barely meet (fig. 6-13). For traffic on business roadways where uniformity of illumination is more important, it may be desirable to narrow the spacing to provide 50-to 100-percent overlap.

MANUFACTURER'S LITERATURE

The performance specifications of each model, type, and size of luminaire are provided with the fixture or obtained from the manufacturer's ordering information. A working knowledge of this information will assist you in selecting and installing the correct luminaire to accomplish the job. Manufacturers provide technical literature for every luminaire they make. This literature includes utilization and isofoot candle curves. These curves are important in calculating the lighting intensity of a particular lumunaire. Figure 6-14 is a sample of manufacturer's literature for a 250- or 400-watt light fixture.

Utilization Curve

The utilization curve (fig. 6-14A), a measure of luminaire efficiency, shows the amount of light that falls on the roadway and adjacent areas. The amount of light that is usable or actually falls on the area to be lighted is plotted as a percentage of the total light generated in the luminaire for various ratios of transverse distance (across the street from the luminaire on both the house side and street side) to the mounting height (fig. 6-15). The coefficient of

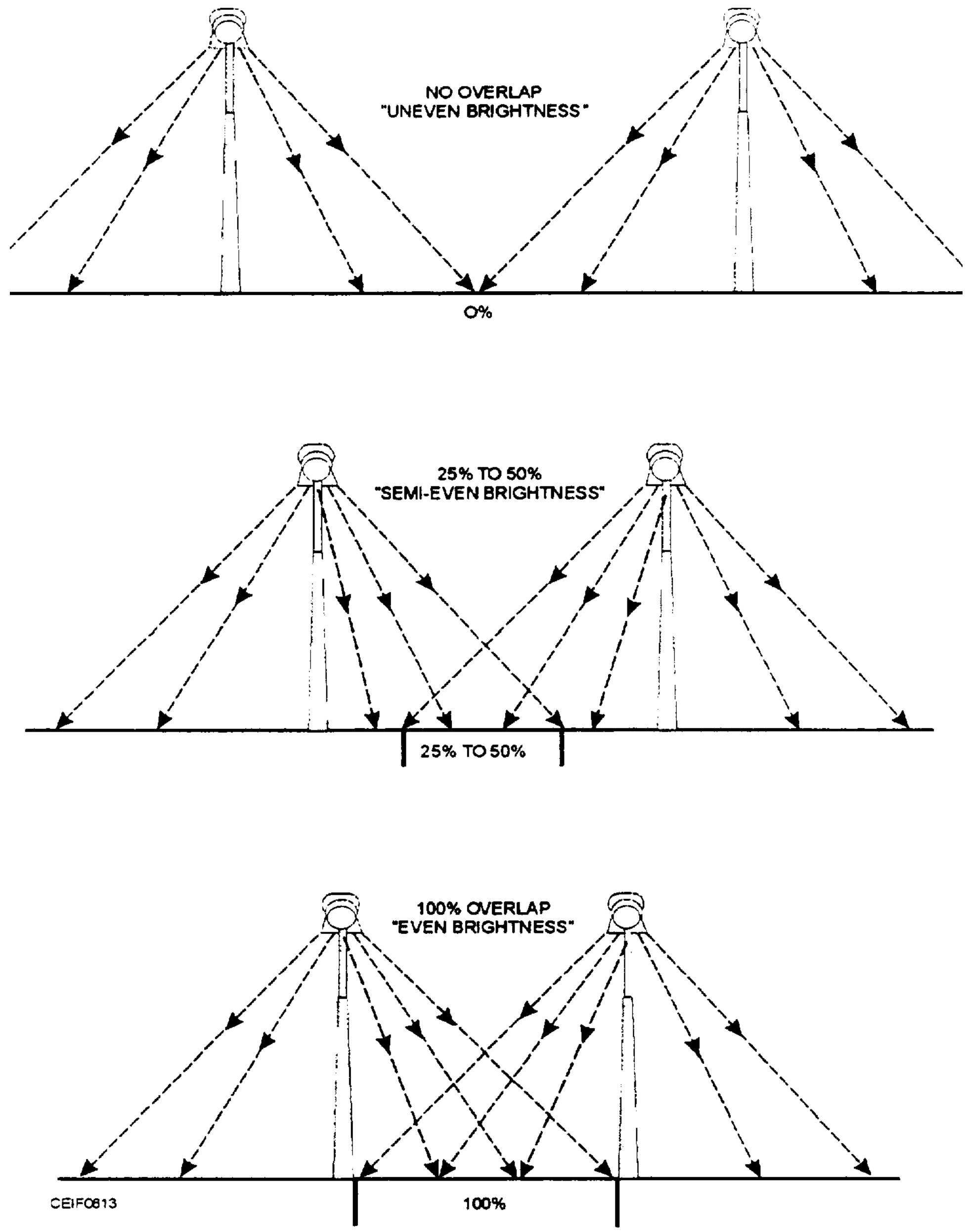


Figure 6-13.—Pavement brightness.

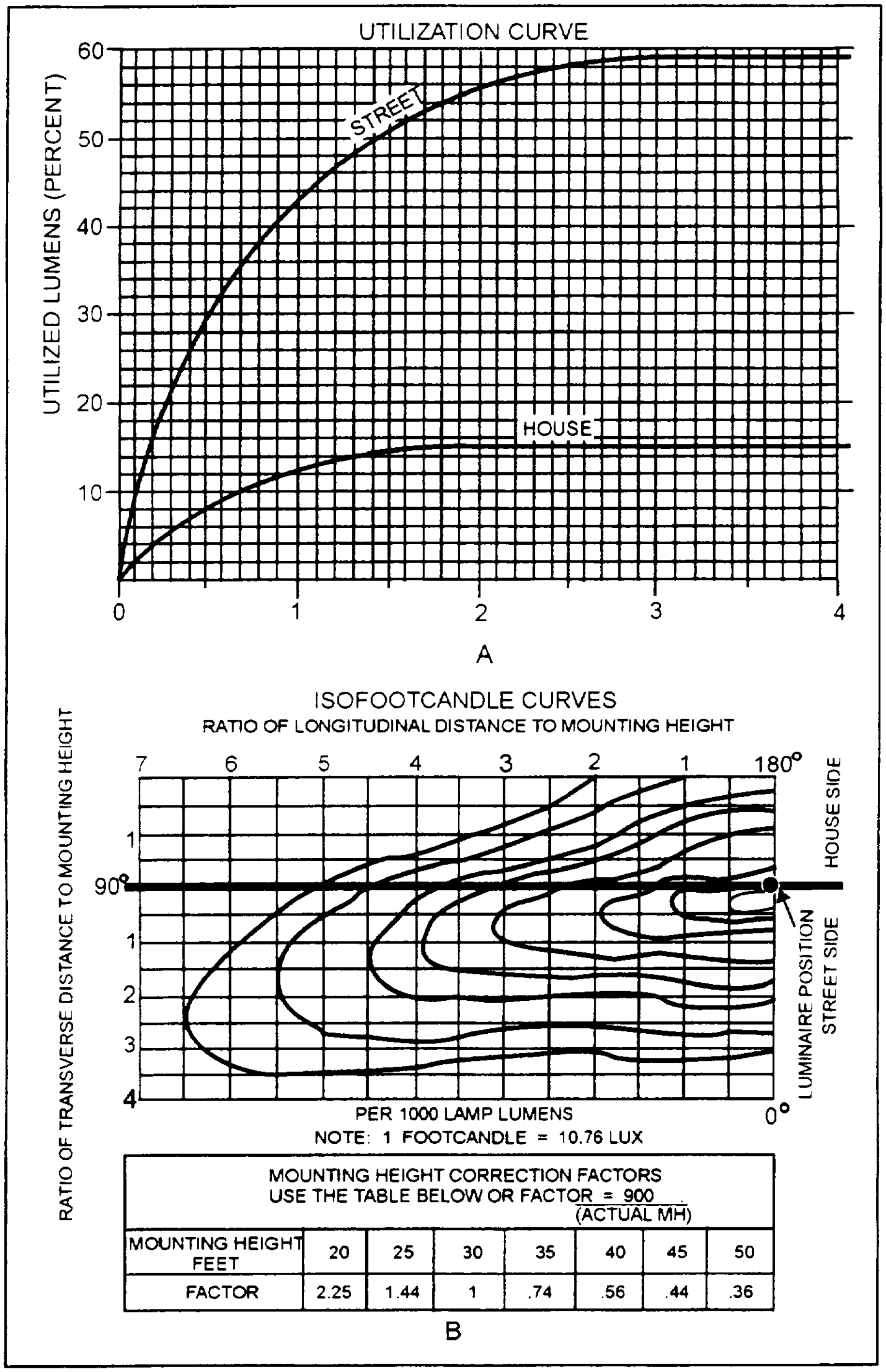
utilization for any specific situation is obtained from this curve. The utilization curve will determine the amount of light that actually strikes the roadway surface. This percentage of light has an impact on the spacing distance of the luminaries.

Isofootcandle Curve

The isofootcandle diagram (fig. 6-14B) shows the distribution of illumination on the road surface in the vicinity of the luminaire.

The lines on this diagram connect all points having equal illumination, much as the contour lines on a topographical map indicate all points having the same elevation. Thus, at any point on the diagram (or roadway), we know the magnitude and direction of the illumination with respect to nearby points. To make this data more universal, you are given both the top horizontal and left vertical axes in terms of mounting-height ratios.

It is sometimes convenient for you to replot the isofootcandle data to the same scale as that used on a drawing containing a lighting layout. By superimposing this diagram, you can study the distribution of light. Under the unity correction factor in the mounting-height table (fig. 6-14B), one can find the mounting height for which the data are calculated. The numbers beside each line represent the initial



MOUNTING HEIGHT FEET	20	25	30	35	40	45	50
FACTOR	2.25	1.44	1	.74	.56	.44	.36

Figure 6-14.—Streetlight manufacturer's literature.

footcandle values per 1,000 lamp lumens. Each footcandle value must be multiplied by 50 to obtain the correct footcandle value on the isofootcandle diagram. This ratio of actual lamp lumens divided by 1,000 is known as the lamp factor (LF). Note that the lamp factor allows a curve to represent the distribution from more than one lamp wattage; for example, from 250- and 400-watt lamps.

Maintenance Factor

Lighting efficiency is seriously impaired by blackened lamps, by lamp life, and by dirt on the reflecting surfaces of the luminaire. Tocompensate for the gradual loss of illumination, you must apply a maintenance factor (MF) to the lighting calculations.

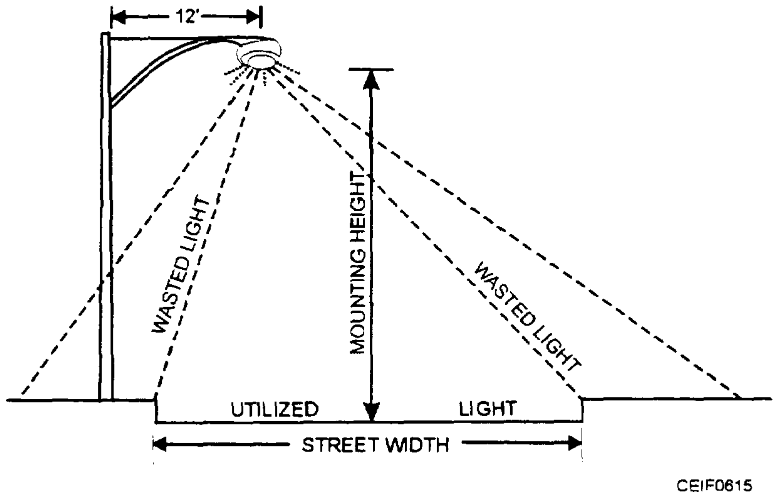


Figure 6-15.—Luminaire utilization.

Normally, each luminaire manufacturer can supply you with the maintenance factor for your lamp model; however, when the manufacturer's information is not available, a 0.70 maintenance factor is widely used in the industry.

LIGHTING INTENSITY CALCULATIONS

Achieving the most satisfactory solution for any given lighting problem requires sound judgment in making necessary compromises of all factors involved.

Selection of the luminaire can be influenced by budget constraints, present stock levels in the Federal Supply System, and availability. Once the luminaire is selected, it is important that you use the manufacturer's literature to determine the number of luminaries, mounting height, and spacing required to produce the desired illumination intensity.

Using the manufacturer's literature supplied in figure 6-14, let us solve this sample problem:

Find:

1. One-sided spacing required to provide specified illumination
2. Uniformity of illumination

Given: (fig. 6-16)

- Street width, 50 feet
- Mounting height, 40 feet
- Pole setback from curb, 2 feet

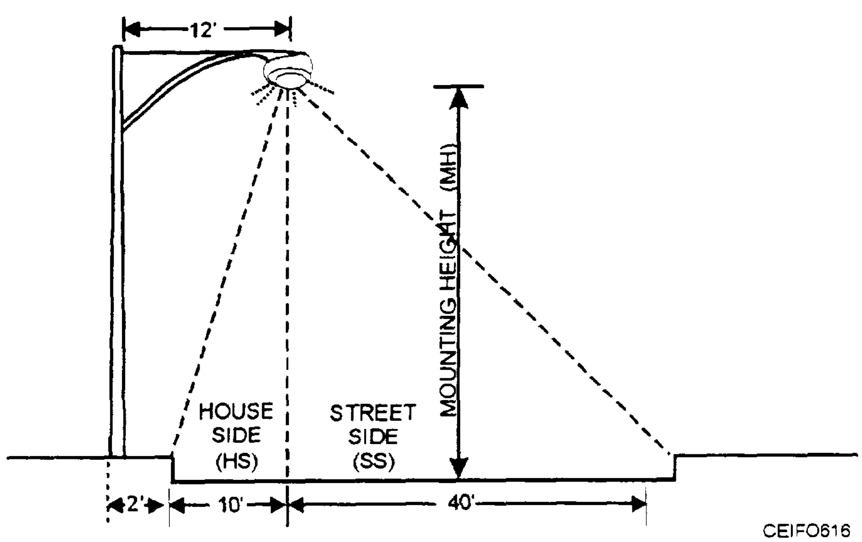


Figure 6-16.—Streetlight sample problem.

- Bracket length, 12 feet
- Required average maintained level of illumination, 2 footcandles
- 400-watt luminaire (50,000 lamp lumens)

Solution:

1. Spacing. The equation to determine correct spacing is

$$Spacing\ (S) = \frac{(LL)(MF)(CU)}{(fc)(W)}$$

Where:

LL = rated initial lamp lumens

MF = maintenance factor

CU = coefficient of utilization

fc = illumination in footcandles

W = street width. curb to curb

The values are given for LL (50.000), MF (assume 0.70). W (50). and fc (2). After a value for CU is determined, you can solve the equation for average spacing.

To determine the coefficient of utilization, calculate the amount of wasted light on the street side (SS) and the house side (HS) where:

$$Ratio\ of\ HS = \frac{Transverse\ \ Distance}{Mounting\ Height} = \frac{10}{40} = 0.25$$

$$Ratio\ of\ SS = \frac{Transversel\ \ Distance}{Mounting\ \ Height} = \frac{50\text{-}10}{40} \quad \frac{40}{40} = 1.0$$

From the utilization curve in figure 6-17, the ratio of 1.0, street side,corresponds to 40 percent. and the ratio of 0.25, house side, corresponds to3 percent. for a total of 43 percent CU.

Spacing can be determined as

$$S = \frac{(50{,}000)\ (0.70)\ (0.43)}{(2)(50)} = 150\ \textit{feet.}$$

2. Uniformity.

The uniformity of illumination is expressed in terms of a ratio of

$$\frac{Average\ fc}{Minimum\ fc}$$

It has been determined that one-side spacing of 150 feet will produce an average of 2 footcandles on the roadway surface. The point of minimum illumination can now be determined from the isofootcandle diagram.

The minimum value of the illumination can be found by studying the isofootcandle diagram and taking into account all luminaries that are contributing significant amounts of light. Generally, the minimum value will be found along a line halfway, between two consecutively spaced luminaries. The minimum value can be determined by. checking the minimum footcandle values at points P1, P2, and P3. as shown in figure 6-18.

The roadway surface can be plotted on the isofootcandle curve by observing the 40-foot mounting height to longitudinal and transverse distance ratios. (See fig. 6-19.) Since PI is located outside the 0.02 footcandle line. it is the lowest total footcandle value. This value would be 0.03 fc (0.015 footcandle from each luminaire).

Figure 6-20 shows a perspective view of the two isofootcandle lines that are considered when determining the illumination value at P1.

The following factors are now applied to this “raw” footcandle value, as shown in the formula:

fc min = (fc) (LF) (MF) (CF)

Where:

fc min = minimum point footcandles

fc = raw footcandle from isofootcandle diagram

LF = lamp factor

MF = maintenance factor

CF = mounting height correction factor

The values are given for fc (0.03) and MF (assume 0.70). The value for LF was determined earlier as 50 for the 400-watt lamp. The CF factor can be determined from the correction chart below the isofootcandle curve in figure 6-14. The CF for a 40-foot mounting height is 0.56.

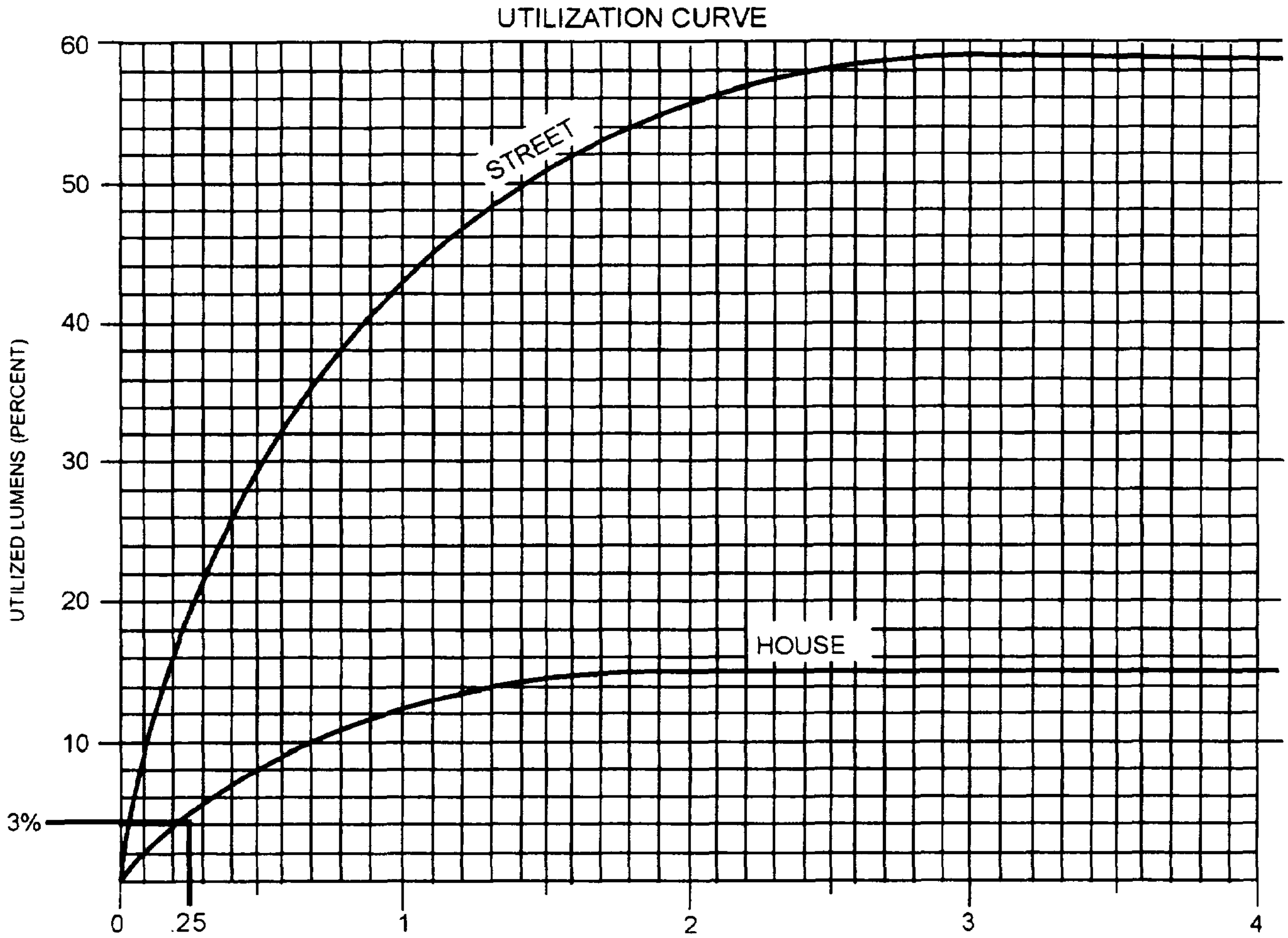


Figure 6-17.—Utilization curve

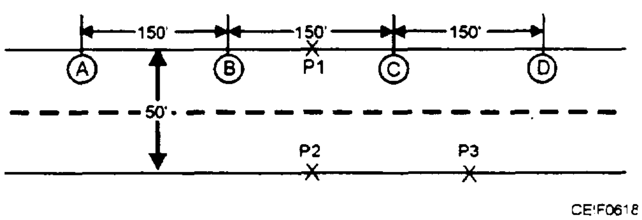


Figure 6-18.—Streetlight layout.

The minimum point footcandies are

fc min = (0.03) (50) (0.70) (0.56) = 0.58

Therefore, the average-to-minimum ratio of uniformity would be

$$\frac{2\ fc}{0.58\ fc} = 3.40$$

A uniformity ratio of 3.40 meets the ANSI/IES recommended roadway illumination levels (table 6-1) for a major, commercial roadway.

FLOODLIGHTS

Streetlighting systems usually give lighting intensity from .01 to 0.5 footcandle; however, this value is too low for any night activity requiring good visibility. Figure 6-21 gives recommended illumination intensities for specific night activities. The following suggestions should be followed to improve the efficiency of floodlighting systems:

- Select floodlight locations so beams strike the surface to be illuminated as nearly perpendicular as possible.
- When lighting irregular surfaces, use two or more floodlights to reduce sharp shadows caused by surface contour.
- For lighting extended horizontal surfaces, such as work areas, mount floodlights high enough to minimize glare.

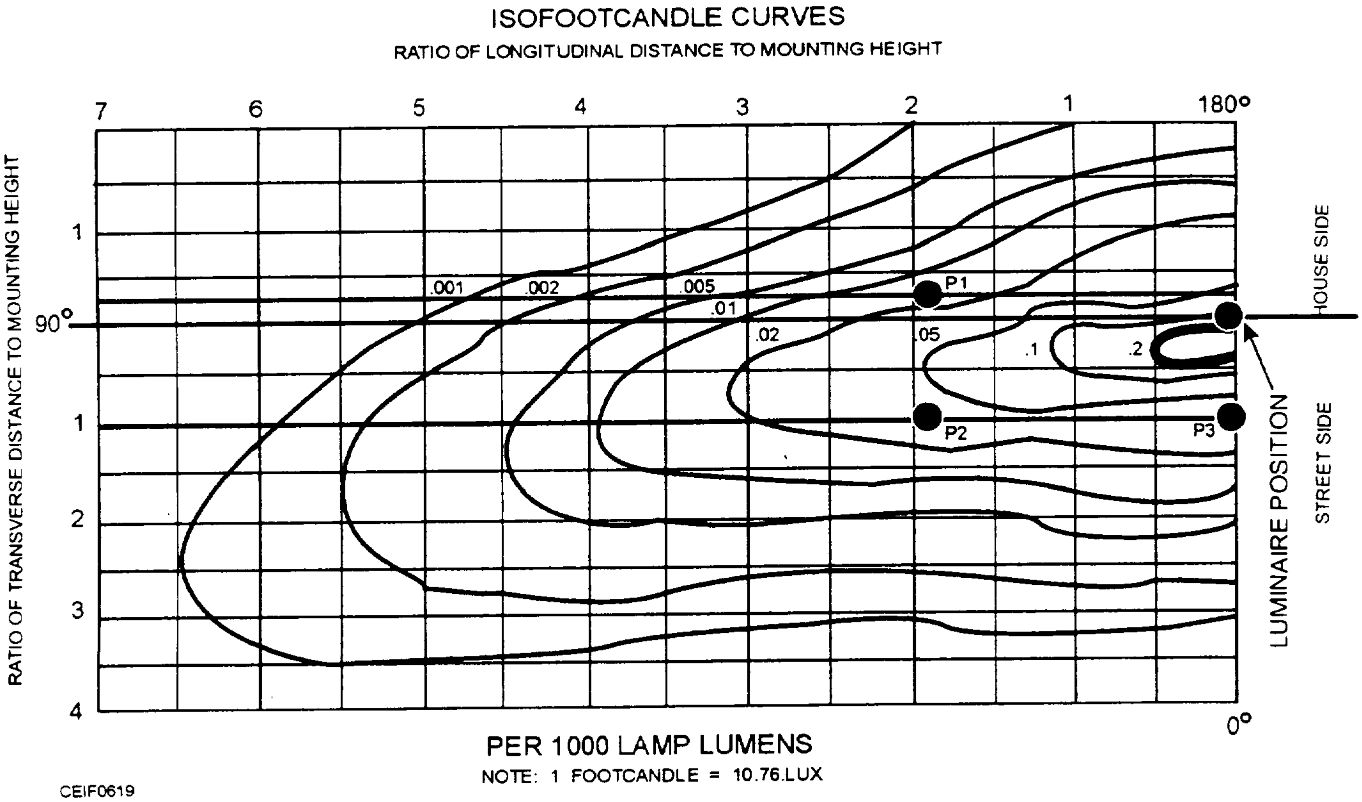


Figure 6-19.—Isofootcandle curve.

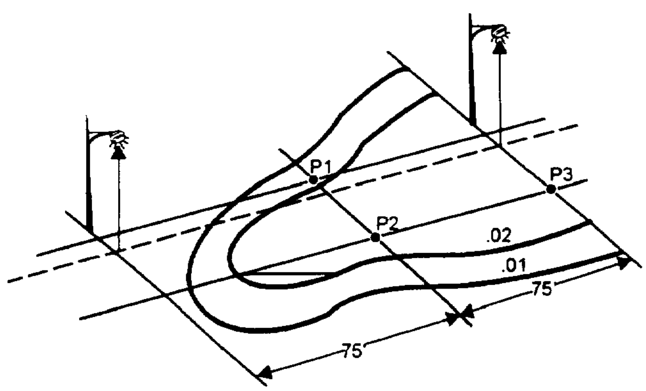


Figure 6-20.—Roadway perspective view.

- For lighting extended vertical surfaces, such as smoke stacks or towers, mount floodlights so distance between floodlights or groups does not exceed twice the distance from the floodlight to the illuminated surface.

- Use a smaller number of large floodlights instead of a larger number of smaller floodlights.

SELECTION OF LUMINAIRES

The National Electrical Manufacturer's Association (NEMA) has classified floodlighting luminaries into four classes according to construction:

1. Class HD (Heavy Duty)—Enclosed with an outer housing into which is placed a separate and removable reflector, or an enclosure in which a separate housing is placed over the reflector

2. Class GP (General Purpose)—Enclosed with a one-piece housing with the inner surface serving as a reflector and the outer surface being exposed to the elements

3. Class O (Open)—One-piece housing without cover glass

4. Class OI—Same as Class O except with an auxiliary inner reflector to modify the beam

The suffix letter "B" should be added to the above class designations to indicate when an integral ballast is required.

Example: A heavy-duty floodlight with an integral ballast would be designated as a Class HDB floodlight.

GENERAL APPLICATION	MINIMUM AVERAGE RECOMMENDED FOOTCANDLES		
BUILDING EXTERIORS	CITY	SUBURBAN	RURAL
- Terra cotta, light marble or plaster	15	10	5
- Bedford or buff limestone, smooth buff face brick, concrete, aluminum	20	15	10
- Smooth or medium gray brick, common tan or dark field gray brick	30	20	15
- Brownstone, stained wooden shingles or other dark surfaces	50	35	20
CONSTRUCTION - General - Excavation	 10 2		
INDUSTRIAL ROADWAYS - Adjacent to buildings - Not bordered by buildings	 10 05		
INDUSTRIAL YARD / MATERIAL HANDLING AREA	5		
LOADING / UNLOADING PLATFORMS, FREIGHT DOCKS	20		
PARKING AREAS - Industrial - Shopping centers - Commercial lots	 10 2 - 5 2 - 5		
SHIPYARDS - General - Ways - Fabrication areas	 5 10 30		
* Outdoor recreational and sporting facilities shoud be based on Illuminating Engineering Society publications.			
All values are considered to be footcandles and are in terms of horizontal-plane. Higher levels of illumination may be required for safety.			

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Figure 6-21.—Recommended intensities for specific night activities.

The beam spread can be described in degrees or by NEMA types (table 6-2). The beam spread is based on the angle to either side of the aiming point where the candlepower drops to 10 percent of its maximum value. The lamp and floodlight NEMA type is given in the upper left-hand corner of each isofootcandle diagram.

The NEMA type should only be used as a reference. It does not describe the shape of the light pattern the floodlight produces or the peak illumination level (footcandles). Symmetrical floodlights have the same horizontal and vertical beam spread and are classified with one NEMA number. Asymmetrical beam spreads have a horizontal (H) and a vertical (V) designation. The horizontal value is always given first.

Example: *NEMA TYPE* $\frac{H}{7} x \frac{V}{6}$

MOUNTING HEIGHT AND SPACING

The size of the area to be illuminated has a direct effect on determining the number and spacing of the poles. The suggested area that can be covered by a single pole is four times the mounting height. That is known as the “2X-4X” rule (fig. 6-22).

Areas lighted from interior poles or other central locations (fig. 6-22A) can be more economical, but

Table 6-2.—Luminaire Designations

			Min. Beam Efficiency %	
Beam Spread Degrees	NEMA Type Designation	Beam Description	Incandescent, Tungsten, Halogen	High-Intensity Discharge
10 up to 18	1	very narrow	38	
18 up to 29	2	narrow	30	30
29 up to 46	3	medium narrow	46	34
46 up to 70	4	medium	50	38
70 up to 100	5	medium wide	54	42
100 up to 130	6	wide	56	46
130 and up	7	very wide	60	50

perimeter locations are also desirable to provide needed visibility at entrances and exits. in the case of perimeter poles (fig. 6-22B), if comer locations are not used, the distance from any side location to the edge of the area should not exceed twice the mounting height. If building-mounted luminaire locations are limited to only one side of the area to be lighted (fig. 6-22C), the system will be effective for a distance of only two mounting heights unless glare is not a determining factor.

According to the 2X-4X rule, the spacing is determined to be, from the corner to the first pole, two times the mounting height(X). The next pole is set four times this mounting height (X), and the CE will continue in this manner until reaching the last pole, which also is to be set two times the mounting height from the far corner. This rule can be used to calculate the minimum number of poles. For long, narrow areas, it is better to choose several short poles than one tall one, especially since pole costs increase substantially above 40 feet. It is wise to consider several alternatives, however. to determine the system with the lowest cost.

If the pole is located inside the area to be lighted, there should be at least three floodlights or two streetlights per pole. For one side perimeter mounting, there should be two floodlights or one streetlight per pole.

FLOODLIGHT AIMING

When a fixture is aimed at the surface at an angle other than perpendicular, the maximum lighting level will always occur behind the aiming point, or point of maximum candela. That is important to know when the fixtures are placed close to the base of a tall structure. In this case, the highest lighting level will occur at the base, even though the fixture is aimed at the top.

For vertical aiming, the aiming point should be two thirds to three fourths of the distance across the area or twice the mounting height, whichever is the lowest value. Higher aiming angles will not improve utilization and uniformity. (See fig. 6-23.)

The highest light level (vertical and horizontal) a floodlight can produce at a distance from the pole occurs when the maximum intensity or candlepower is aimed to form approximately a three, four, five triangle. (See fig. 6-24.) That is useful when determining pole height for area lighting or setback for building floodlighting.

Floodlights with NEMA 6 or 7 horizontal beams will effectively light an area 45 degrees to either side of the aiming line. In figure 6-25, the perimeter pole needs at least two floodlights to cover the area in all directions. Narrower beam floodlights require less separation to achieve uniform lighting.

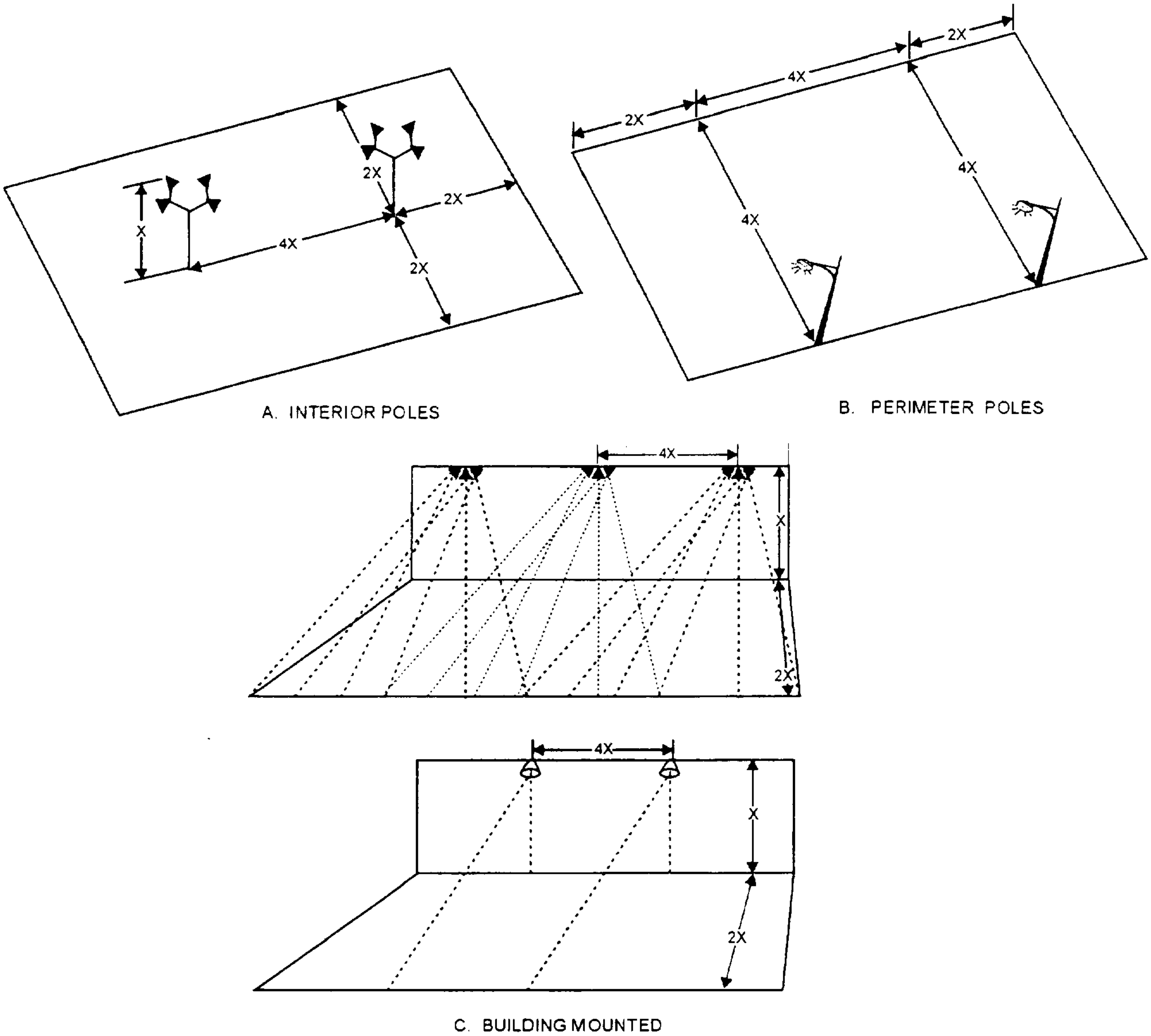


Figure 6-22.—2X-4X mounting height rule.

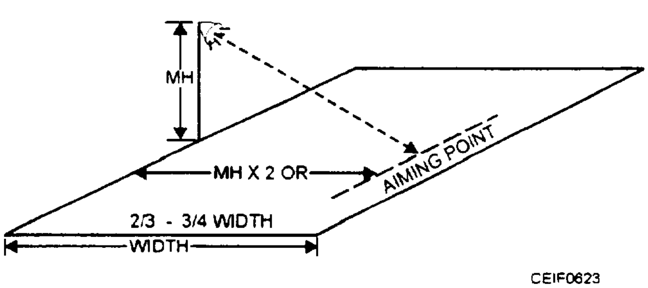


Figure 6-23.—Vertical aiming.

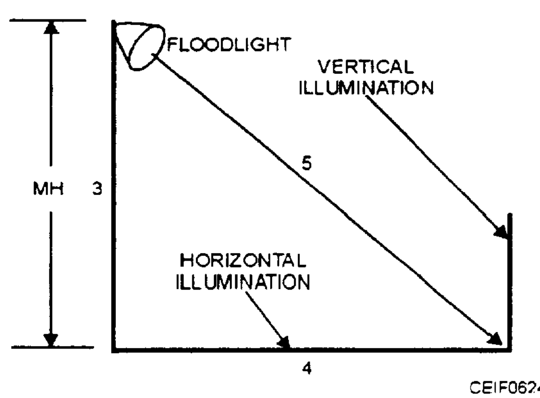


Figure 6-24.—Maximum candlepower of illumination.

NEMA TYPE	HORIZONTAL BEAM SPREAD	SUGGESTED MAX. AIMING LINE SEPARATION
2	18° - 29°	12°
3	29° - 46°	24°
4	46° - 70°	40°
5	70° - 100°	60°
6	100° - 130°	90°
7	130°	120°

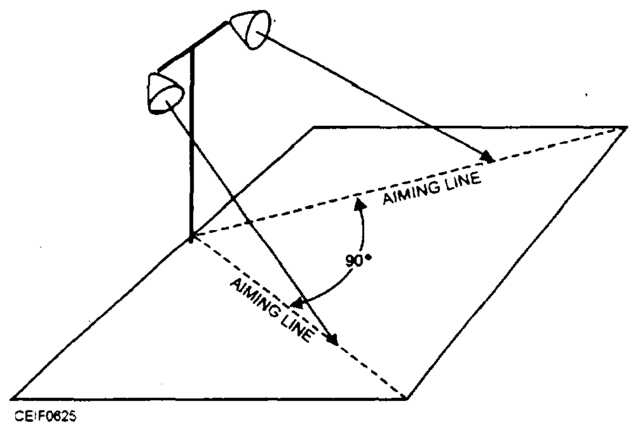


Figure 6-25.—Horizontal aiming.

Select lighting fixtures with a beam spread greater than the area being lighted. When several units are required, good lighting overlap occurs when the edge of the beam of one fixture coincides with the aiming point of the adjacent fixture.

By examining the shape (beam spread) of the lighting pattern emitted by the fixture, you can begin the process of selecting the NEMA type of floodlight best suited for the application.

Horizontal and vertical lumen distribution is stated on each photometric test. Generally, the more concentrated the luminous intensity (candela), the tighter the beam spread; for instance, the NEMA Type 2 Power Spot® floodlight has a beam spread of 22-degrees horizontal by 21-degrees vertical; whereas, a NEMA Type 5 has a beam spread of 77-degrees horizontal by 77-degrees vertical. The isofootcandle diagrams shown in figure 6-26 compare 1,000-watt metal halide Power Spot® luminaries of NEMA Type 2 and Type 5 when each luminaire is aimed out a distance of twice its mounting height.

The initial footcandle level at the aiming point of different NEMA types varies a great deal; for example, assume that each luminaire is mounted at a 50-foot mounting height and aimed 100 feet (2 x MH) directly in front of its location. If you are using a NEMA Type 2 distribution, the approximate initial footcandle level at that point would be 20; however, if you are using a NEMA Type 5 distribution, the initial footcandle level would be approximately 1.5.

By understanding the intensity of the lighting pattern, you can now appreciate the need for a range of distribution patterns.

MANUFACTURER'S LITERATURE

The performance specifications of each model, type, and size of luminaire are provided with the fixture or obtained from the manufacturer's ordering catalog. A working knowledge of this information will assist you in selecting and installing the correct floodlight to accomplish the job. Figure 6-27 shows a sample of manufacturer's literature for a 250- to 1,000-watt light fixture.

INITIAL FC TABLE			
	MOUNTING HEIGHT		
	40	50	60
A	0.16	0.1	0.07
B	0.31	0.2	0.14
C	0.78	0.5	0.35
D	1.6	1.0	0.69
E	3.1	2.0	1.4
F	7.8	5.0	3.5
G	15.6	10.0	6.9
H	31.2	20.0	13.9

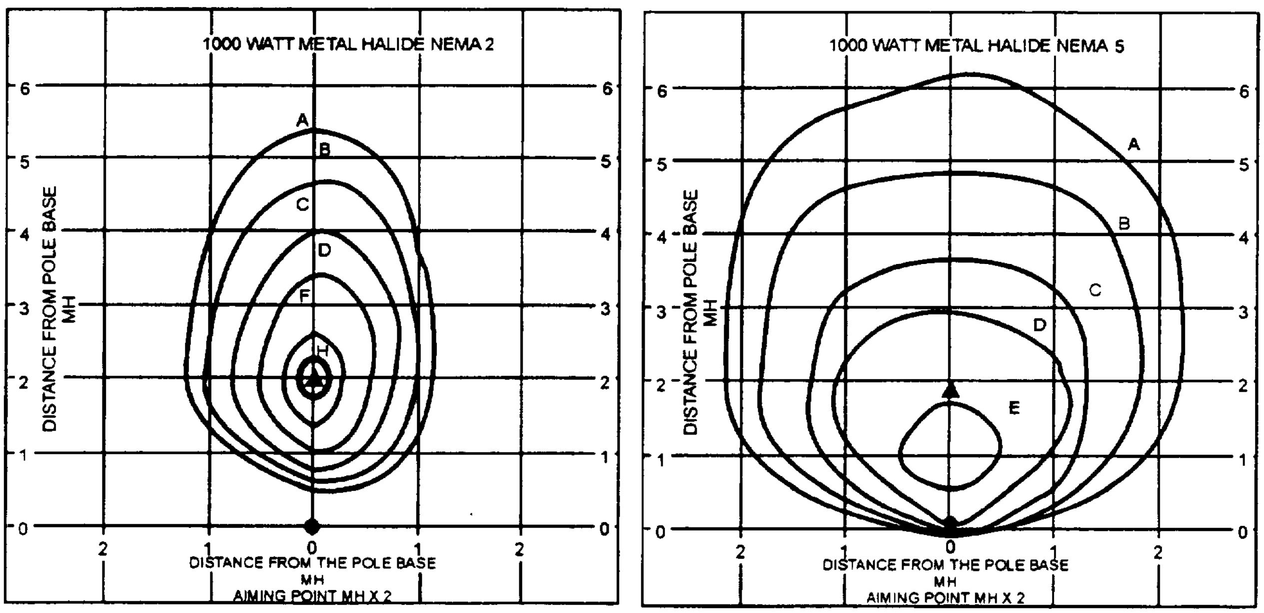


Figure 6-26.—Isofootcandle diagrams.

ISOFOOTCANDLE DIAGRAMS

The isofootcandle diagrams show what the light level will be at any given point. The dimensions for the diagram are based on the mounting height (MH) of the floodlight. The aiming point (▲) is also based on the mounting height. Figure 6-27 provides a diagram for mounting heights of MH x 0.5, MH x 1, and MH x 2.

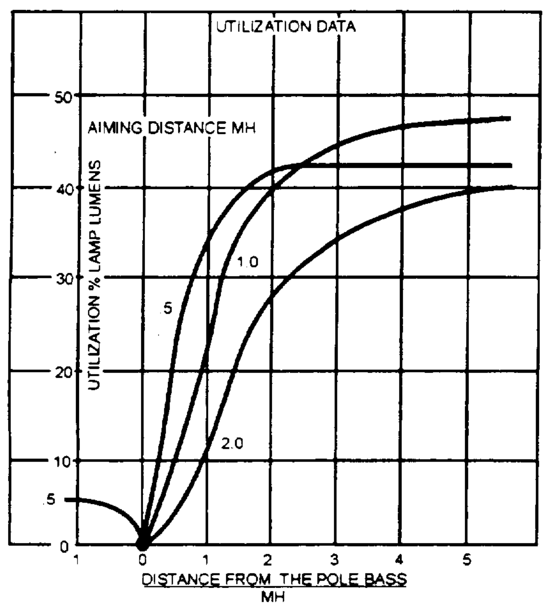
The grid pattern is also based on the mounting height. The grid line values left and right give the distance to either side of the floodlight. The values up the side show the distance in line with the aiming direction of the floodlight. The number 3, for instance, represents 3 x 40, or 120, feet from a 40-foot mounting height.

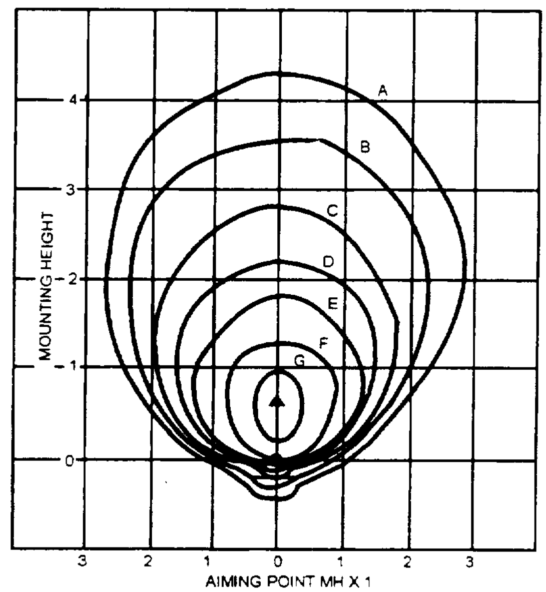
Each isofootcandle line shows where the footcandle level is the same. These lines are identified by a letter, which is used with the initial footcandle (fc) table. The footcandle values between isofootcandle lines do not change more than 2 to 1. That makes it possible to approximate the level between lines.

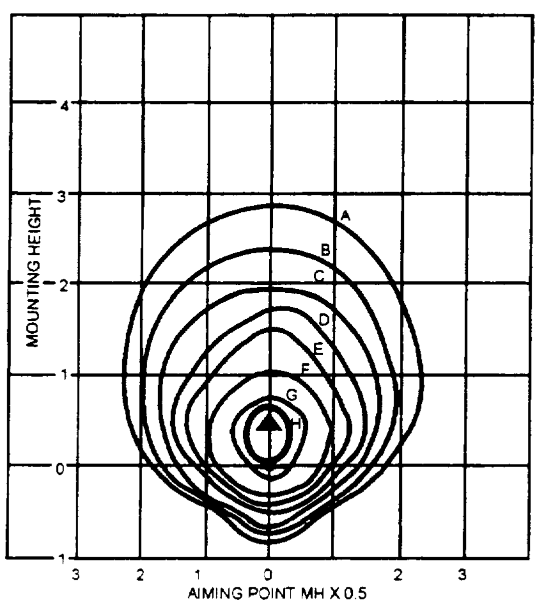
INITIAL FC TABLE LU 250 watt			
	30	40	50
A	0.05	0.33	0.02
B	0.11	0.06	0.04
C	0.31	0.17	0.11
D	0.61	0.34	0.22
E	1.2	0.69	0.44
F	3.1	1.7	1.1
G	6.1	3.4	2.2
H	9.2	5.2	3.3

INITIAL FC TABLE LU 400 watt			
	30	40	50
A	0.10	0.06	0.04
B	0.22	0.13	0.08
C	0.56	0.31	0.2
D	1.1	0.63	0.4
E	2.2	1.3	0.8
F	5.6	3.1	2.0
G	11.1	6.4	4.0
H	16.7	9.4	6.0

INITIAL FC TABLE LU 1000 watt			
	40	50	60
A	0.16	0.1	0.07
B	0.31	0.2	0.14
C	0.78	0.5	0.35
D	1.6	1.0	0.69
E	3.1	2.0	1.4
F	7.8	5.0	3.5
G	15.6	10.0	6.9
H	23.4	15.0	10.4







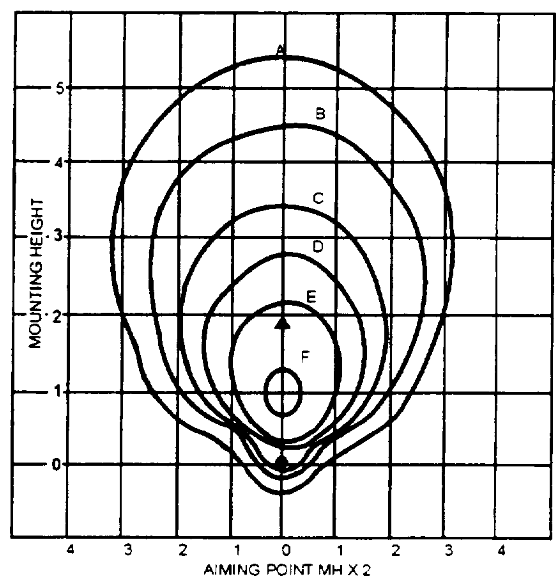


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Figure 6-27.—Floodlight manufacturer’s literature.

The initial footcandle table gives the footcandle value for each isofootcandle curve at a specific mounting height. The values for each letter are the same on each set of curves. That makes it possible to compare diagrams directly and interpolate between curves for different aiming distances.

The mounting heights given in the initial footcandle table are representative of the wattage and beam pattern associated with the floodlight. To convert to other mounting heights, use the following formula:

$$\frac{\text{OLD}}{\text{(FROM CHART)}} \qquad \frac{\text{NEW}}{\text{(FROM CALCULATION)}}$$

$$(fc)(MH^2) \qquad (fc)(MH^2)$$

For example, a 5-footcandle level at 50 feet (isofootcandle curve F) would have a value of 4.13 at a 55-foot mounting height.

$$(5)(50^2) = (fc)(55^2)fc = 4.13$$

In figure 6-27 (aiming point MH x 2), the floodlight is aimed a distance of two mounting heights away from a point on the ground directly below the floodlight. That would be 80 feet for a 40-foot mounting height.

UTILIZATION GRAPH

The luminaire utilization data graph (fig. 6-27) gives the percentage of the initial lamp lumens that fall into the area being lighted. Knowing this, you can easily determine the average lumens per square foot, or footcandles.

The number beside each curve identifies the aiming point, so that the utilization curve can be identified with the associated isofootcandle diagrams. In the example, for instance, the floodlight aimed two mounting heights away from the pole would have a utilization of 35 percent if it were lighting an area three mounting heights wide. The same floodlight aimed at one mounting height away from the pole would have a utilization of 45 percent for the same area.

MAINTENANCE FACTOR

Lighting efficiency in floodlighting, as in streetlighting, is seriously impaired by blackened lamps, by lamp life. and by dirt on the reflecting surfaces of the luminaire. A maintenance factor (MF) must be applied in the lighting calculations to compensate for the gradual losses of illumination on the lighted area.

The following maintenance factors have been widely used in industry when manufacturer's information is not available:

Enclosed flood lamps, 0.76

Open flood lamps, 0.65

LIGHT INTENSITY CALCULATIONS

There are a number of ways by which to determine luminaire requirements. Since most methods would require an engineering background, we will only discuss the basic area lighting design considerations that you, as a Construction Electrician, can perform in the field if engineering assistance is not available. To better understand how the calculations are performed, solve this sample problem:

Determine the average, initial light level in a 160-foot x l60-foot material storage yard using two NEMA 6 x 5 HLX 1,000-watt floodlights.

Solution:

1. Apply the 2X-4X rule (fig. 6-28) to determine spacing and mounting height. A 40-foot mounting height provides MH x 2 or an 80-foot aiming distance.

2. The formula used to calculate the average, initial light level (fc) is as follows:

$$fc = \frac{(N)(LL)(CU)}{AREA}$$

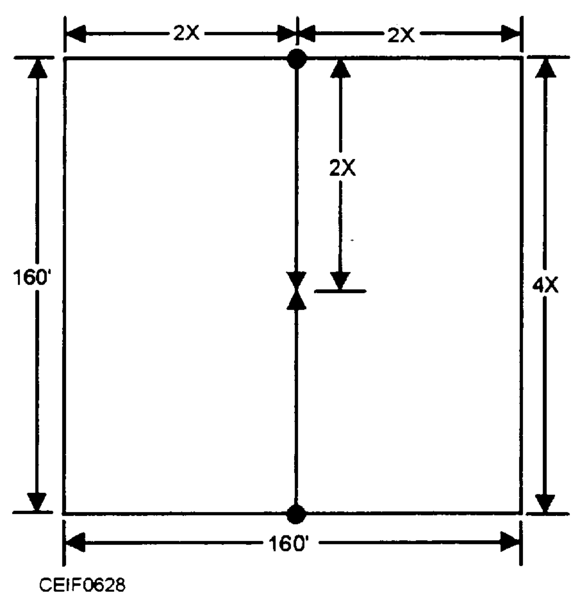


Figure 6-28.—Material yard sample problem.

Where:

N = number of floodlights

LL = initial lamp lumens

CU = utilization of the floodlights

From the utilization data (fig. 6-27), you can find that the utilization for the HLX luminaire aimed at two mounting heights across an area 160 feet or four mounting heights wide is 38 percent. The initial lumens for the 1,000 watt lamp are 140,000 lumens, obtained from the manufacturer's literature. Substituting in the formula,

$$fc = \frac{(2)(140{,}000)(0.38)}{(160)(160)} = 4.2\ fc$$

The maintained light level is obtained by multiplying the initial light level by the maintenance factor.

$$fc = (4.2)(0.75) = 3.15\ fc$$

Using the isofootcandle diagram, we obtain point by point footcandle values: for example, the center of the area occurs just inside isofootcandle line E. From the initial footcandle table, the 1,000-watt HLX at 40 feet produces 3.1 footcandles at line E and 7.8 at line F. Since the point is approximately one fourth of the distance between the two isofootcandle lines, the value will be about 4.0 footcandles. With the two floodlights contributing, the value in the center will be 8.0 footcandles. Note that the corners of the area will have very little light. That is why two or more floodlights are recommended at perimeter locations.

Another design method that will yield sufficient accuracy is the quick selector design method. The general layout considerations shown in figure 6-28 should be followed. The watts per square foot obtained from the graph in figure 6-29 produce an average lighting level accurate to within 20 percent of desired value. That is close enough, since the difference between the luminaire requirement obtained from the graph and the number that will actually be needed to satisfy the physical requirements of the job involve adjustments greater than 20 percent. It is not unusual, for instance, to need two poles instead of one or to require three luminaries per pole instead of two. This calculation method should not be used for sports lighting or where the poles are set back from the area to be lighted.

Before determining the number of luminaries, you should work out the size of the area to be lighted. Also, you should determine the maintained illumination level. The following rules of thumb provide some guidelines to help in these decisions.

1. From figure 6-21, you find that the minimum average footcandles recommended for industrial yard/material handling is 5.

2. Read up the left side of the graph in figure 6-29 until you come to 5. Follow this line across until you intersect the dark diagonal line representing Lucalox®.

3. By reading straight down from this intersection to the value at the bottom of the chart, you find 0.095 lamp watts/square foot of the area is required to light the yard to 5 footcandles.

4. Area to be lighted is (160)(160) = 25,600 square feet.

5. Multiply 25,600 by 0.095 = 2,432 lamp watts.

   2,432 is more than two 1,000-watt Lucalox® lamps

   2,432 is approximately equal to six 400-watt Lucalox® lamps

   2,432 is approximately equal to ten 250-watt Lucalox® lamps

6. By using the general layout considerations, you will find that the most economical floodlight installation will use the 400-watt Lucalox® lamps, mounted on 40-foot poles, as shown below.

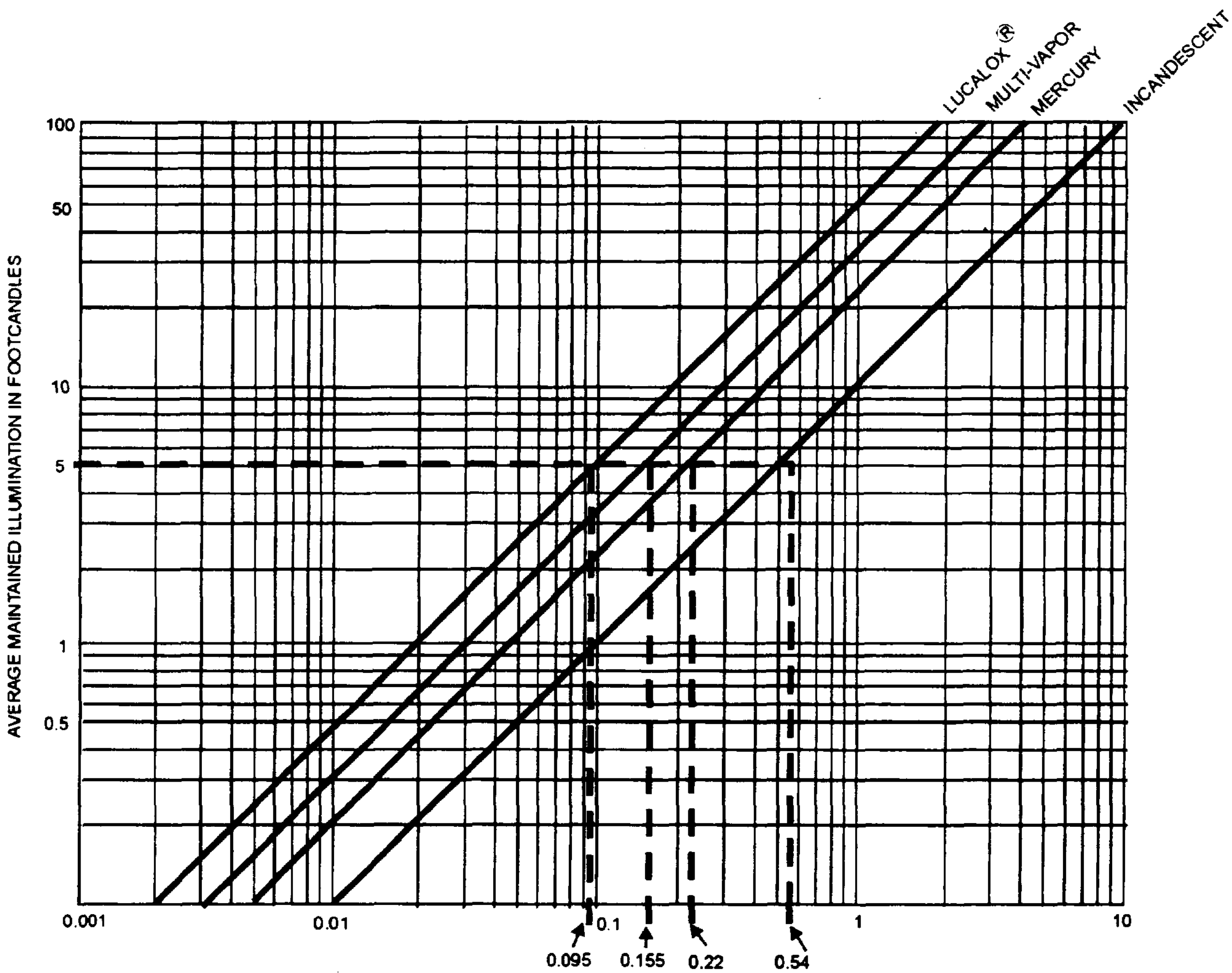
$$2X + 2X = 4X = 160 \text{ feet}$$

$$X = \frac{160\ feet}{4} = 40\ feet\ MH.$$

SECURITY LIGHTING

Requirements for security lighting at activities will depend upon the situation and the area to be protected. Each situation requires careful study to provide the best visibility that is practical for guard duties, such as identifying personnel and vehicles, preventing illegal entry, detecting intruders, and investigating unusual or suspicious circumstances.

The type of security lighting may be either the continuous or the standby type. The continuous type, as the name implies, is on all the time during the hours of darkness. The standby type is activated either manually or automatically when suspicious activity is detected.



EXAMPLE: TO PRODUCE A MAINTAINED LEVEL OF 5.0 FOOTCANDLES OVER A LARGE AREA, THE FOLLOWING WATTS-PER-SQUARE-FOOT WILL BE REQUIRED:

LUCALOX® - 0.095 MULTI-VAPOR - 0.155
MERCURY - 0.22 INCANDESCENT - 0.54

CEIF0629

Figure 6-29.—Lamp watts per square foot chart.

SECURITY AREA CLASSIFICATION

The installation of security lighting is set forth in *United States Navy Physical Security Manual,* OPNAVINST 5530.14. It provides specifications on searchlights and minimum footcandle requirements under given situations. The illumination of boundaries, entrances, structures, and areas must be according to the security manual.

LIGHTING CONTROL

Each security lighting system is designed to meet a particular need of the activity. The design is such that it provides the security required at maximum economy.

Multiple circuits may be used to advantage here. The circuits are so arranged that the failure of any one lamp will not darken a long section of the area. The protective lighting system should be independent of other lighting systems and protected from interruption in case of fire.

The switches and controls of the system should be locked and/or guarded at all times. The most effective means is to have them located in a key guard station or central station similar to the system used in intrusion alarm central station installations.

ALTERNATE POWER SOURCES

In general, any security area provided with protective lighting should have an emergency power source located within that security area. The emergency power source should be adequate to sustain all security requirements and other essential service required within the security area. Provisions should be made to ensure the immediate availability of the emergency power in the event of power failure. Security force personnel should be capale of operating the power unit. If technical knowledge prevents this, plans must provide for responsible personnel to respond immediately in times of emergency. In addition, battery-powered lights and essential communications should be available at all times at key locations within the secure area.

AIRFIELD LIGHTING

As a Construction Electrician second class petty officer. you may be responsible for the installation of expeditionary airfield lighting and any repairs or maintenance required to the installation as well as to permanent advanced base launch and landing facilities.

Since the Seabees existence is based on being used in contingency operation, you should know the equipment and components of such a contingency lighting system. The “Expedient Airfields Facility,” 13610A, as taken from the Advanced Base Functional Component Facility Listings, provides such information. If the world situation should develop to a point where the Seabees are alerted and tactical air support is required, such a kit would accompany you to the forward area. For contingency operations, the types of airfields used may be any of the following:

1. Vertical takeoff and landing (VTOL) airfields
2. Vertical short takeoff and landing (VSTOL) airfields (600 and 1,800 feet)
3. Expeditionary airfield (EAF)
4. Strategic expeditionary landing field (SELF)

The scope of this chapter is not to provide details on the electrical systems used at each of the above-mentioned airfields but rather to acquaint you with the components of the systems and their functions for both expeditionary and permanent airfields.

Normally, the VTOL airfield is an installation made of aluminum matting and is used as a forward landing field by either helicopters or Harrier type of aircraft; whereas, the VSTOL airfield, also an aluminum matted installation, is usually used as a forward operational facility. The EAF is used by high-performance aircraft and is also used as a forward air facility. The SELF is similar to the EAF, but with a longer runway.

AIRFIELD LIGHTING SYSTEMS

Airfield lighting systems are designed to aid pilots during launch, recovery, and taxi operations. The reasons for these systems date back to the days of smudge pots and the burning of brush piles to help guide pilots into safe landings. Through the years, the methods of lighting airfields have become much more sophisticated. The lighting systems today have the light properly distributed, have light controls, and also have the ability to define certain areas by means of different colored lenses and filters inside of the lighting fixtures.

The patterns and colors of the light, as well as the markings, at each airfield are uniform to enable the pilots to interpret what is seen and then to react almost automatically. To ensure that airfield lighting standards are met, the Federal Aviation Administration (FAA) has been tasked with developing the standards and with the policing authority to ensure compliance within the United States. In addition, FAA standards are used in airfields constructed by the military overseas.

The design of airfield lighting systems must provide for locating an obstructional warning system, runway and approach markings, and taxiway and parking facility markings.

AIRFIELD LAYOUT

The VTOL forward operating site is a portable airfield of minimum size designed for operations dependent upon logistic or tactical support by helicopters and other vertical takeoff or landing aircraft. The field consists of a surface pad 72 feet square, as shown in figure 6-30, view A, without lighting, communications, or recovery systems.

A VSTOL facility is a portable airfield capable of providing support to VSTOL fixed-wing aircraft as well as helicopters. The field consists of a surfaced runway 900 feet long and 72 feet wide and turnoff, parking, and maintenance areas. The nature of the aircraft to be serviced precludes the necessity for arresting gear; however, a field lighting system and a communications system are supplied to provide suitable aircraft recovery capability. A VSTOL facility can readily be converted to a VSTOL air base.

A VSTOL air base also is a portable airfield capable of providing support for VSTOL fixed-wing aircraft as well as helicopters. The field consists of a surfaced runway 1,800 feet long and 72 feet wide and turnoff, maintenance, and parking areas to

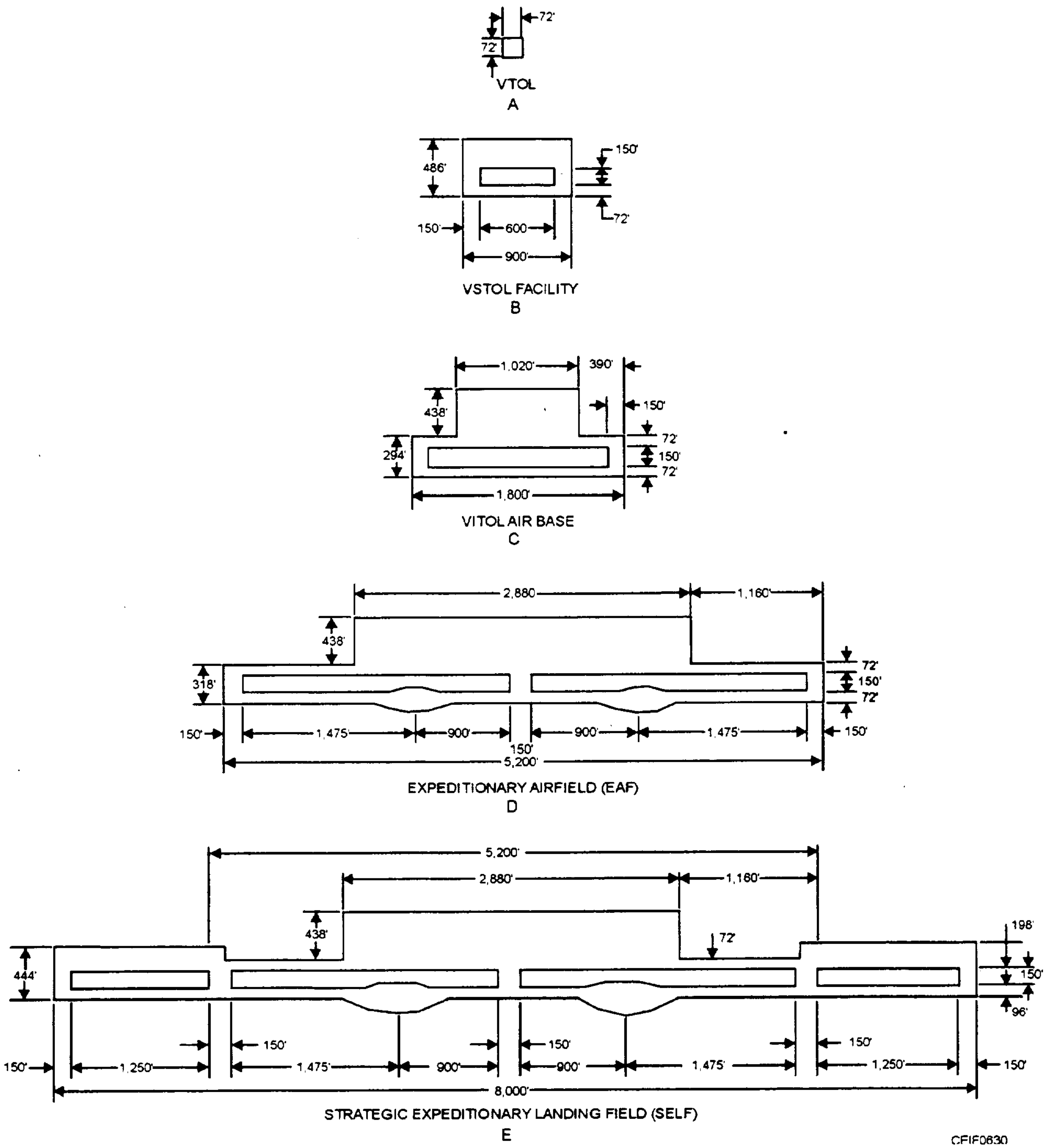


Figure 6-30.—Field arrangement direct installation.

accommodate up to 12 aircraft. From the VSTOL air base assets, plans are provided from which three VSTOL FACILITIES can be constructed. The VSTOL air base can support at least one squadron of light VSTOL attack aircraft and a number of helicopters. The nature of the aircraft serviced by the VSTOL air base precludes the necessity for arresting gear; however, a field lighting system, a Fresnel® lens optical landing system (FLOLS), and a communications system are incorporated to provide suitable aircraft support. A VSTOL air base readily may be converted to an expeditionary airfield (EAF).

The EAF is a portable airfield that provides a surfaced runway 5,200 feet long and 96 feet wide, as shown in figure 6-30, view D, and parking and maintenance areas for up to six squadrons of light-to-medium fighter/attack aircraft, in addition to a complement of reconnaissance aircraft and helicopters. The field includes two M-21 aircraft recovery systems. two FLOLS, and field lighting and communications systems. An EAF may readily be converted to a strategic expeditionary landing field (SELF).

The SELF is a portable airfield that provides a surfaced runway 8,000 feet long and 96 feet wide, as shown in figure 6-30, view E. The SELF is a pre-positioned war reserve (PWR) setup. The airfield provides turnoff, maintenance, and parking areas to accommodate up to six squadrons of light-to-medium fighter/attack aircraft, a detachment of tanker aircraft, and various transient logistic support aircraft. The SELF configuration includes two M-21 aircraft recovery systems as well as two FLOLS and field lighting and communications systems.

AIRFIELD LIGHTING VAULT

The beginning of the airfield lighting system is the airfield lighting vault. The primary power feeder enters the vault and supplies power to all of the major components. These components, in turn, control and operate the airfield lights. The vault houses the high-voltage power cables, the current regulators, the relay cabinets, and the control panels.

The control cables are installed between the vault and the control tower or other control points. The high-voltage cables are connected to the regulators and run out to the lights. The lighting control panels are used to give local/remote control of the system. The same type of remote control panel that is in the vault should also be installed in the control tower.

The airfield lighting vault should be about 3,000 feet from the runway. This distance ensures that no interference will occur with the operation of the airfield, and still. it is not so far away that voltage drops might cause a problem. The lengths of the control circuits between the control tower and the vault are limited by operational characteristics; for example, size of field, obstructions, and so forth. The minimum distance is 350 feet; that is to prevent the equipment in the vault from causing radio interference. If the control cable leads terminate into actuating coils of relays in the pilot relay cabinet, the maximum distance is 7,350 feet.

Safety

The airfield lighting vault should have certain items of safety equipment affixed to a board. This board should be an open display and easily accessible. It should be a minimum of 1/2 inch thick and 4 by 4 feet in width and length. The color should be dark green with white letters and borders.

On this board, some of the safety items you should have are as follows:

1. Operating instructions for the equipment in the vault
2. Resuscitation instructions
3. A phone and a list of emergency phone numbers
4. A first-aid kit
5. A switch stick with a minimum length of 5 feet and a 300-pound pull ability
6. A hemp rope, l/2 inch thick, with a minimum length of 15 feet
7. Insulated fuse pullers (for secondary cartridge fuses)
8. A nonmetallic-encased flashlight marked with luminescent tape to aid in its location in the dark
9. A shorting stick
10. Rubber gloves

For the safety of personnel, the airfield lighting vault must be grounded. That may be accomplished by using two 1/2-inch-diameter, 8-foot-long, copper-plated electrodes, driven into the ground about 8 feet apart and connected in a loop with the vault or ground cable part of the ground grid. This typical connection is shown in figure 6-31.

Power Supply

In many cases, the power supply will not be all high or low voltage. In fact, in many expeditionary airfields, the system may be a combination of high and low voltage. However, if you are assigned to a naval air station, chances are that you may be required to maintain high-voltage airfield lighting systems. Basically, the systems are identical, but because of safety requirements, the high-voltage systems will have a few variables. As an example, take the isolation transformer (IT) in the high-voltage system; it serves to step the voltage down, but its primary purpose is to prevent an opening in the primary series loop when a lamp failure occurs. In a low-voltage system, the transformer is usually a 2: 1 or 1: 1 ratio unit that serves to maintain a closed loop-the same function as the one in the high-voltage system. Even though we will

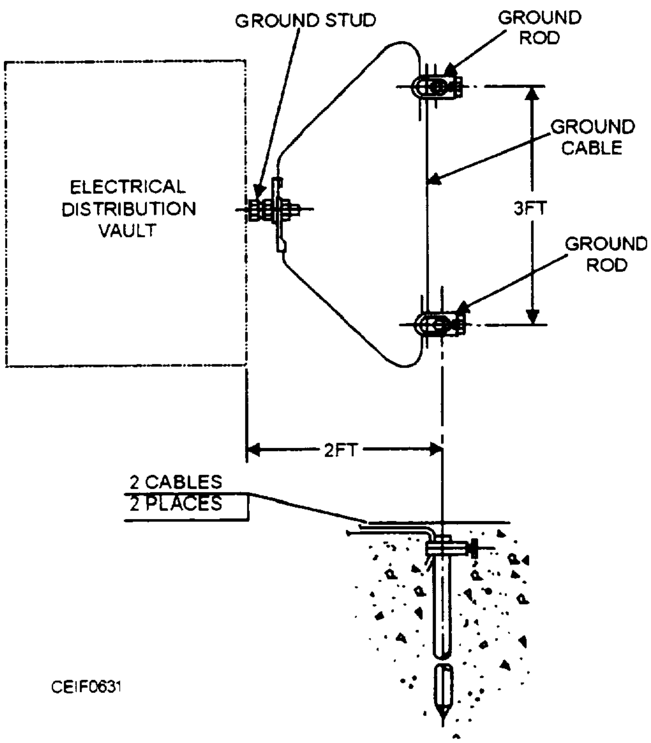


Figure 6-31.—Vault grounding arrangement.

be talking primarily about high-voltage systems most of the time, the functions of the components will apply to either system.

In the 2,400/4,160-volt system, the four-wire wye primary source is usually from the base electrical system by means of either an overhead or an underground line. Inside the vault, the lines are connected to a suitable switch, then to a bus system consisting of heavy metal bars that are supported on insulators. This bus system may be mounted on either the wall or the ceiling.

The bus is divided into a high-voltage (2,400-volt) bus and a low-voltage (120/240-volt) bus for service as follows: the 2,400-volt bus supplies all of the 2,400-volt regulators and one or more distribution type of transformers. The distribution transformers supply 240 volts to the low-voltage bus that is connected to the regulators operating from this lower voltage as well as for light and power inside the lighting vault.

Where an emergency power supply is available for airfield lighting, a changeover switch makes the primary connection to the bus. This changeover switch in its normal position connects the bus to the base power source. Changing the switch to the emergency operation position connects the bus to the emergency power and, at the same time, disconnects the base power source.

Emergency power can be supplied by a completely automatic engine-driven generator; for example, failure of the base power causes the engine to start. In a matter of seconds, the changeover switch automatically shifts to the emergency position, connecting the generator to the airfield lighting bus.

At many advance bases, this automatic feature may not exist. You would have to hook up the proper sized generator manually. The generator should have a kilowatt (kW) rating capable of handling the airfield lighting systems, runway edge lights, threshold lights, approach lights, distance markers, optical launching system (OLS), and other circuits that may be used. The generator is three phase; its voltage output varies from 120/240 volts delta or 120/208 volts wye to 2,400/4,160 volts, and it has to be capable of being operated at frequencies of 50 or 60 hertz (Hz).

Constant-Current Regulator

Runway lighting systems are supplied from series circuits served by constant-current regulators (CCRs). Each lighting circuit on the airfield has a separate regulator. The CCRs maintain the output current throughout its rated output value, depending on the load. Some of the regulators are equipped with brightness controls. These brightness controls adjust the brightness of the lamps in the lighting system to compensate for visibility conditions.

The CCR uses solid-state devices to maintain a constant-current level in its respective lighting system. The regulators are silicon-controlled rectifiers (SCRs) in a feedback circuit to obtain a constant-current output instead of resonant circuits, moving transformer elements, or saturable reactors. The SCRs are controlled to vary the part of a cycle during which the current is permitted to flow into the load circuit. In the load circuit, the current is maintained constant at any value preset with the brightness control by means of a feedback circuit as the load resistance is varied from maximum to zero. The block diagram (fig. 6-32) shows the elements constituting the regulator. Load current is measured by the current transformer and the Hall unit, or multiplier unit, that has an output voltage proportional to the square of the load current. The Hall unit, or multiplier, output is filtered and fed into the input of an amplifier and compared with an input from a brightness control potentiometer. The output voltage is a function of the difference between the two inputs.

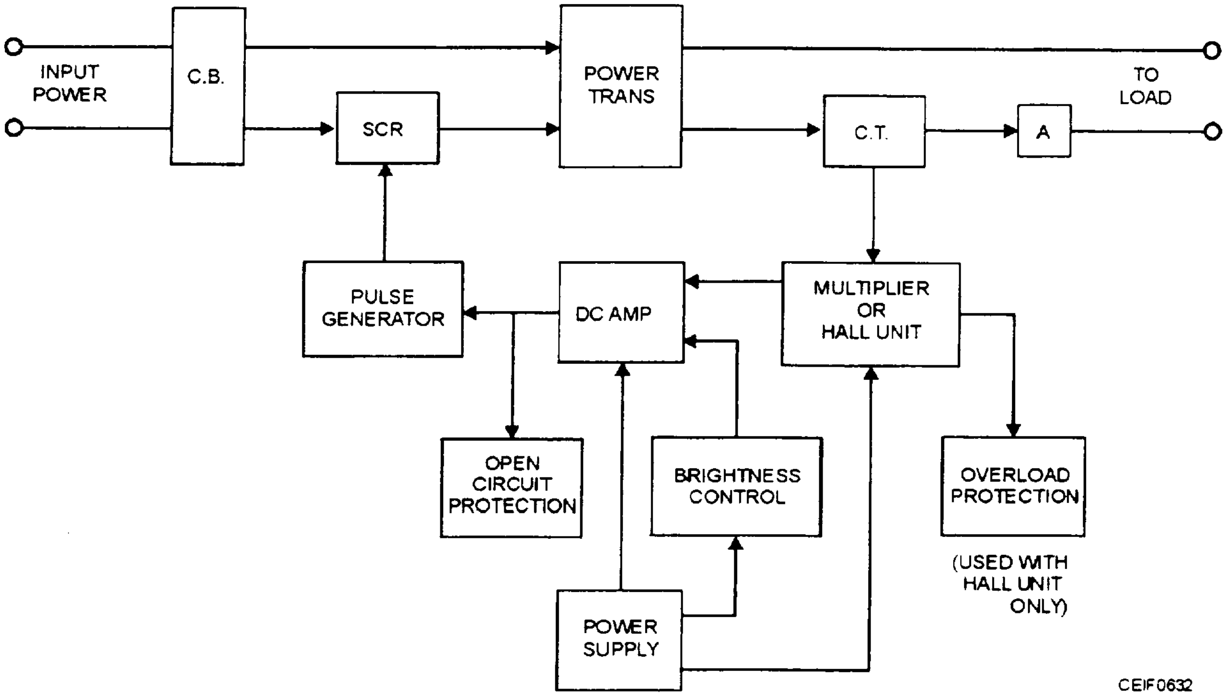


Figure 6-32.—Block diagram of constant-current regulator.

The output voltage is applied to the input of the gate pulse generator that determines the condition angle of the SCRs and changes it to bring the system to equilibrium. Transient overload protection is provided for the semiconductor element of the Hall unit. Open-circuit protection is provided when no current is drawn by the load and the brightness potentiometer output voltage is any value other than zero. Under these conditions, the SCRs will be prevented from conducting, and the output voltage to the load will be zero.

Remote Control

The airfield lighting systems may be operated completely by the remote control panel assembly. The only operation required at the electrical distribution vault is to ensure that all circuit breakers are engaged, the regulators are set for remote operation, and the load switches are in the ON position. The electrician must ensure that the unit is installed properly and that the different levels of light intensity desired can be achieved. Figure 6-33 is a typical view of a remote control unit that you may encounter in the installation of a contingency airfield lighting system.

The unit uses 120 volts as the control voltage with low-burden pilot relays to compensate for the voltage drop caused by the long distances usually found between the control tower and the vault. In this type of control system, the switches on the control panel actuate low-burden relays; these, in turn, actuate the power switches, contactors, and the relays controlling the regulators that supply the airfield lighting circuits.

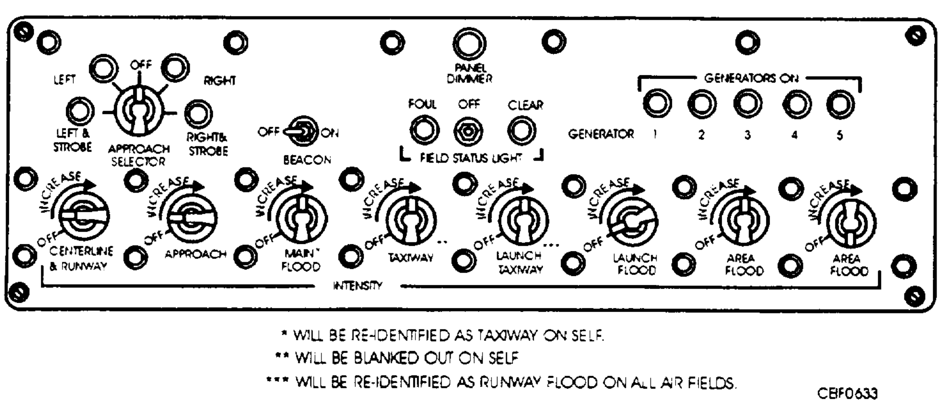


Figure 6-33.—Typical remote control panel operating controls.

Both the tower and vault control panels are wired into a double-throw "transfer-relay cabinet" located in the vault. That is shown in figure 6-34 with a single line representing the control cable. The transfer relay can connect either control panel to the pilot-relay cabinet. It can switch the system control from the tower to the vault or from the vault to the tower. The transfer relay has an eight-pole, double-throw, transfer-relay assembly unit. This unit is actuated by a toggleswitch.

The low-burden pilot relay is designed to operate at a wide range of voltages lower than the designed 120-volt ac rating. The pilot relay can be actuated at voltages from 50 to 90 volts ac.

The standard control cable is a No. 7 conductor, 600-volt, insulated, polychloroprene-sheathed cable. One conductor (black) is a No. 12 American Wire Gauge (AWG), and the remaining conductors are No. 16 AWG. The No. 12 conductor is the hot lead, and the No. 16, the "switch legs."

LIGHTING CIRCUITS

Several different lighting circuits are used on airfields: runway edge lighting circuits, taxiway lighting circuits, approach lighting circuits, obstruction lighting circuits, beacon lighting circuits, and the

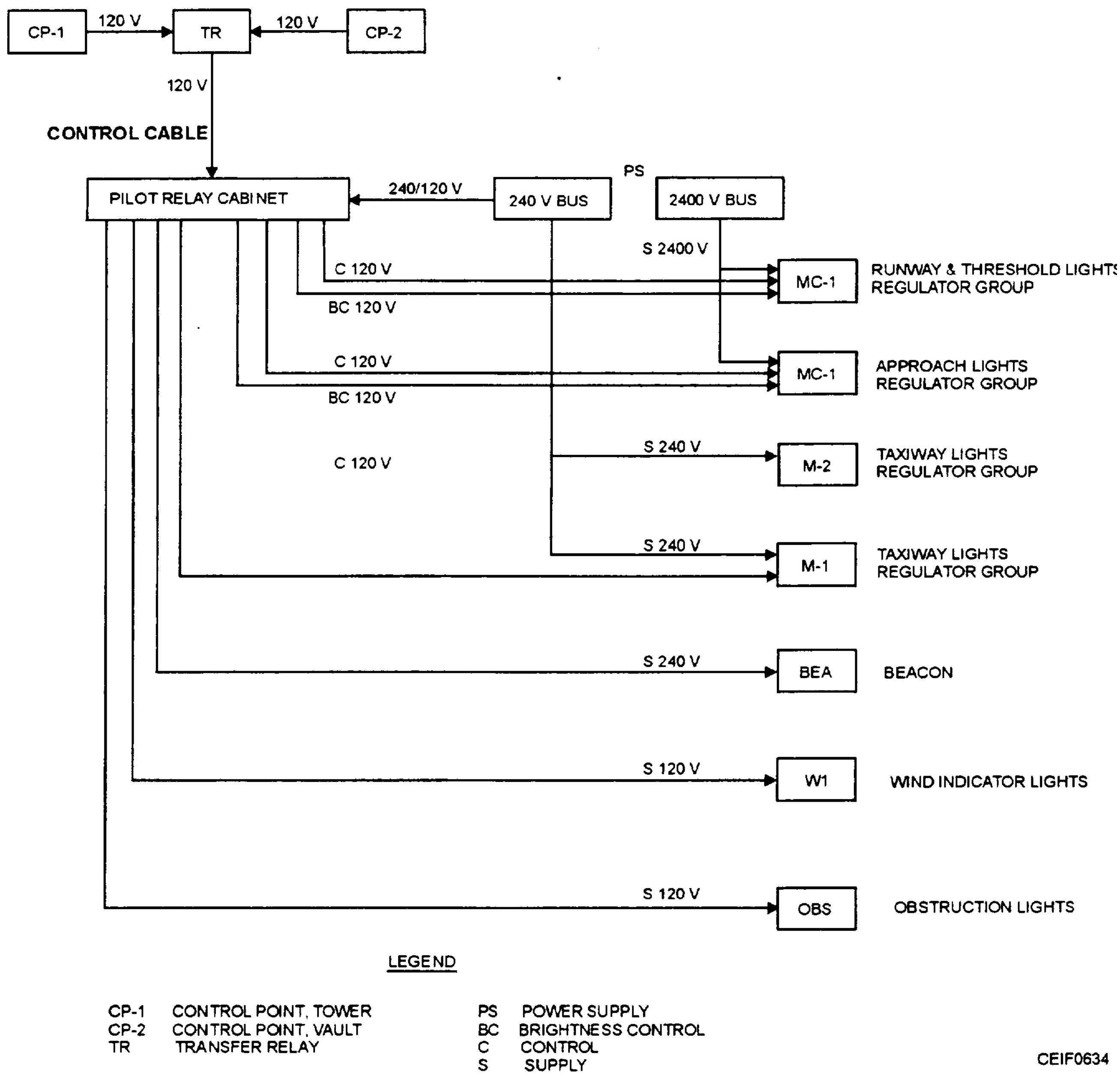


Figure 6-34.—Airfield lighting control system

and the condenser discharge circuits. Each of these circuits will be covered separately.

Runway Edge Lights

Runway edge lighting is designed to show the width and length of the usable landing area; there are two rows of lights—one row on each side—that run the length of the runway. The light they give off is aviation white (clear). The edge lights are installed not more than 10 feet from the edge of the full-strength runway paving. Both lines of lights will be the same distance from the runway center line. It is best if the lines of lights are located as close to the runway as the base mounting for the lights allows. The lights are equally spaced along the runway at distances not to exceed 200 feet. (See fig. 6-35.)

The runway lighting controls are set up so that the lights on intersecting runways cannot be on at the same time. Also. the controls must turn all the light systems of one runway on at the same time. The runway edge lights are controlled so all the lights are the same brightness. In a high-intensity system, threshold lights are one step higher than the runway edge lights except when the runway edge lights are at full brightness. At this time. both the runway edge lights and the threshold lights are at full brightness. In a medium-intensity runway lighting system, all lights (runway edge lights and threshold lights) are the same brightness.

In some instances, it is a good practice to use runway edge light fixtures and lamps for the threshold lights, so that the difference is noticeable when the threshold lighting configuration has to be stepped up one brightness higher than the runway edge lights. To determine the number of circuits required for runway edge lights, you need to determine the length of the runway. You determine the number of lights on one circuit by considering not only the number of lights connected to the circuit but also the voltage loss for the circuit cables and the feeder cables from the vault to the runway. If this distance is long, you may need to adjust the number of lights in the circuit.

Do not load the regulator less than one half of its rated kilowatt (kW) output. If more than one regulator is required, each regulator should be equally loaded.

Each light circuit will be fed by a series loop. The current leaves one terminal of the CCR, goes through the circuit to each light unit, and returns to the other terminal of the regulator.

Taxiway Lights

Taxiway lights are used to show the pilot the width and direction of the “taxiing route.” The lights are aviation blue in color. They are basically the same as runway lighting circuits.

Approach Lights

Runway approach light systems are used on high-intensity-equipped runways. The system starts at the threshold and extends outward for 3,000 feet. When the full length of the land cannot be used, the greatest length possible is used. Condenser discharge (strobe) lights that put out a high-intensity, bluish white light start at the 3,000-foot mark and flash in sequence toward the threshold. The system is used to help the pilots land under low-visibility conditions. The condenser discharge lights are discussed in more detail later in this chapter.

The lights of the approach system are located on an imaginary line that extends from the runway center line. Each light bar is centered on this imaginary line and spaced the same distance apart for the entire 3,000 feet.

The supply and control circuits of the approach lighting systems are installed underground and are usually in conduit; however, in some cases, the last 2,000 feet of the approach lights can be above ground. In some cases, the supply cable from the series circuit can be direct burial.

Aboveground circuits may be used for approach lighting when the cables do not present a hazard to vehicular traffic or are not accessible to unauthorized personnel and animals. The cable must be installed, normally, a minimum of 22 feet above ground. Where the area is completely closed off (fenced): a lower ground clearance is acceptable. Control circuits may use a small-size conductor when it is supported by a messenger cable. DO NOT USE ALUMINUM CONDUCTORS. Use standard overhead construction practices for series circuits. Use lightning arresters when the cables go from underground to overhead. Connect the ends of the circuits in the same way as underground cables.

Besides the basic runway light configuration, there are other airfield lighting aids to help the pilot in landing and takeoff operations. Four such aids for landing and taking off are the visual approach slope indicators (VASI), the Fresnel® lens optical loading system (FLOLS), the runway distance markers, and the threshold lights.

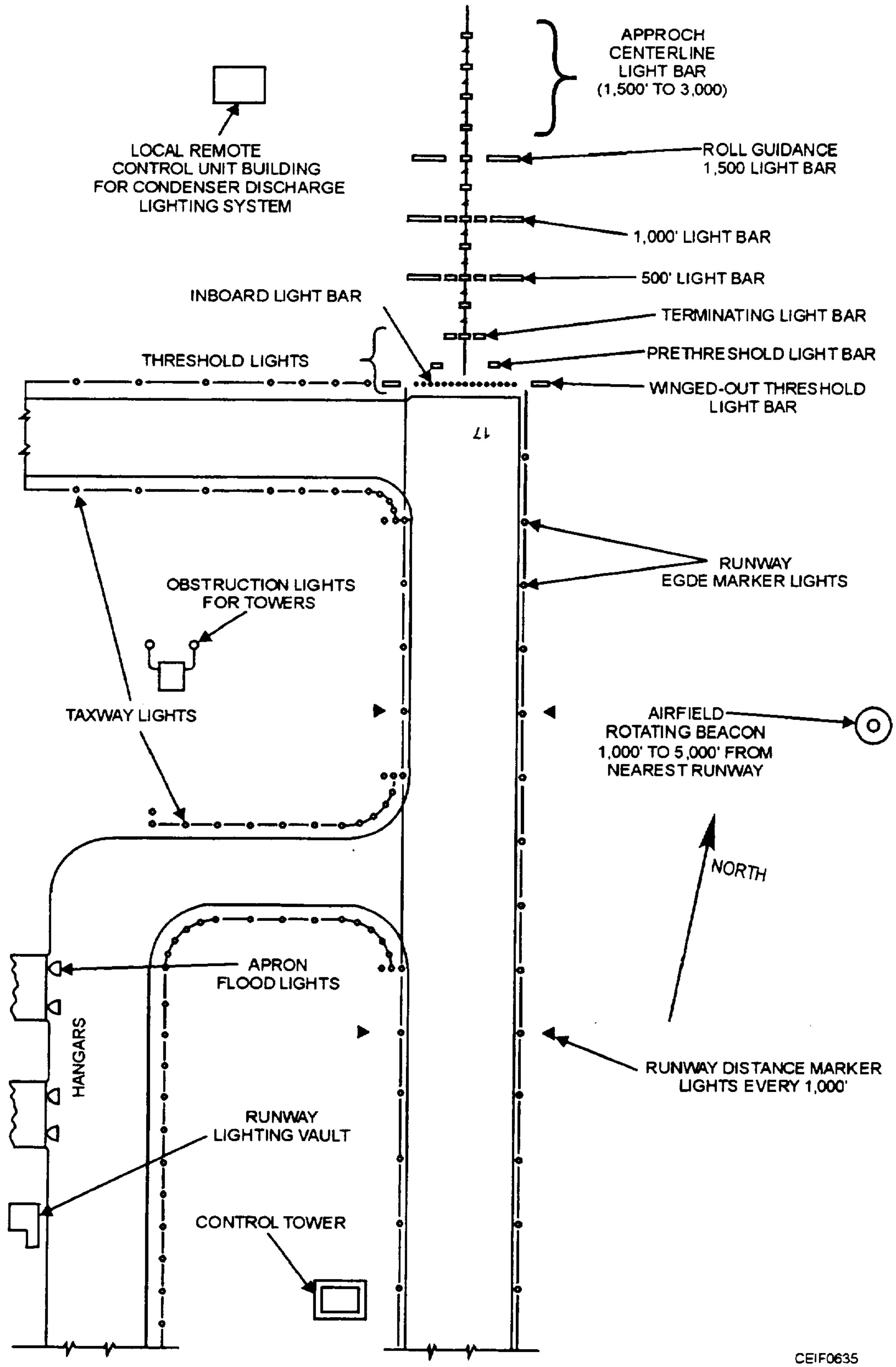


Figure 6-35.—Typical airfield lighting layout.

VISUAL APPROACH SLOPE INDICATORS (VASI)—The VASI system provides the pilot with visual approach slope angle information while on final approach. The VASI system is helpful during daylight or night operations. There are three standard VASI system configurations: VASI-4. VASI-12, and VASI-16. We will discuss the VASI-12 system as it will appear on most Navy airfields.

The VASI system consists of twelve light boxes with three lights in each box. There is one complete system for each end of the runway. There are two pairs of bars-one pair of bars on each side of the runway. Each wing bar is composed of three light boxes (fig. 6-36). The set of bars nearest the threshold is called the downwind bars. and the other pair. the upwind bars. Each light box projects a beam of light that is white (clear) in its upper part and red in its lower part. The lights are arranged so that the pilot of an airplane, during the approach. sees all of the wing bar lights as red when below the glide slope. When on the glide slope. the pilot sees the downwind bar lights as white and the upwind bar as red. When above the glide slope, the pilot sees all the wing bar lights as white.

FRESNEL® LENS OPTICAL LANDING SYSTEM (FLOLS).—Another system designed for continuous automatic operation is the FLOLS. (See fig. 6-37.) It also provides optical landing assistance by indicating the correct glide slope angle to the pilot of an approaching aircraft. This system contains two groups of horizontal datum lights set perpendicular to the approach path; two vertical bars of wave-off lights; two double types of cut lights; and a source light indicator assembly, consisting of five vertical cell assemblies. Each cell assembly contains source lights, a Fresnel® lens. and a lenticular lens. The arrangement of these lenses gives the pilot the glide slope. The unit should be set up on the left side of the runway, from the pilot's perspective, about 10 feet from the edge of the pavement and 750 feet from the runway threshold.

Power for the system is provided by an installed field lighting supply or by an auxiliary, power unit capable of 20 kilowatt (kW). 60 hertz (Hz), three-phase, 120 volts phase to neutral.

RUNWAY DISTANCE MARKER.—With the use of high-speed aircraft, the runway distance marker system is needed to tell the pilots how much runway is left to take off or to land. The distance information, in thousands of feet, is given by numbers on the side of the marker. The numbers are on two sides of the signs, so that the distance left can be shown for both directions. There is one row of signs on each side of the runway. Each row is the same distance from the runway center

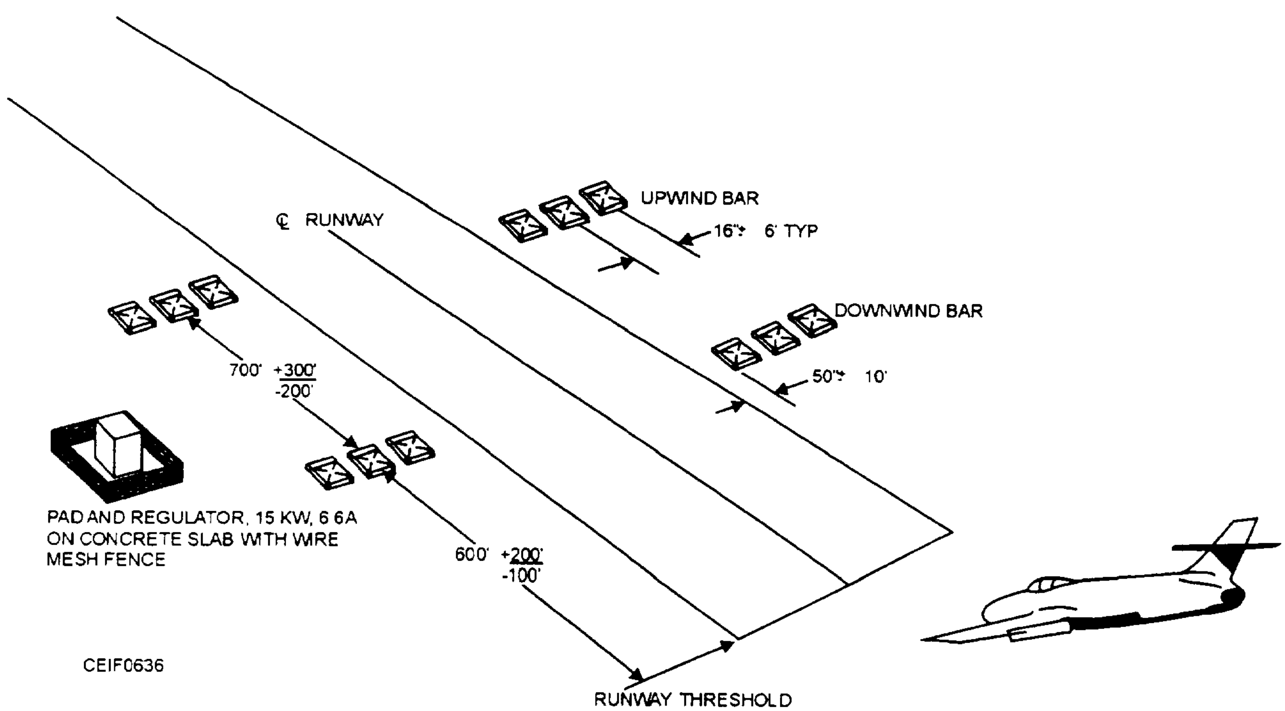


Figure 6-36.—Visual approach slope indicators (VASI).

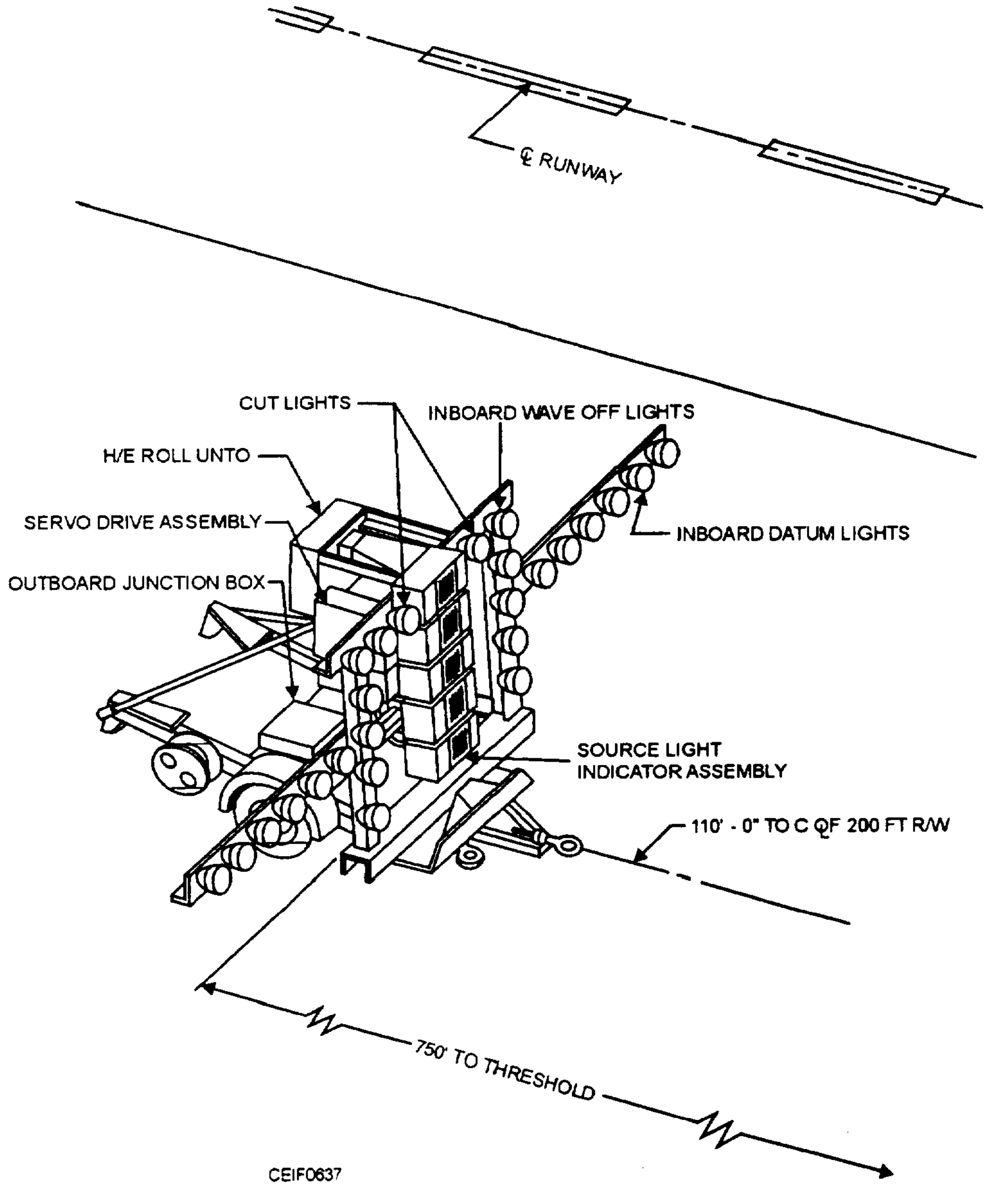


Figure 6-37.—Fresnel® lens optical landing system (FLOLS).

line. They are spaced 1,000 feet apart. The signs have painted numbers that are lit so they can be seen at night and during periods of restricted visibility.

The power supply for serving the runway distance markers should be from a separate series circuit. Do not have the markers supplied from circuits feeding either the runway, threshold, or the approach lighting circuits, since these circuits are operated at various brightness steps, and the signs are operated at their full brightness at all times. Also, do not connect them to taxiway circuits because of the intermittent operation requirements. The cable used for the runway distance marker circuit is a single conductor, No. 8 AWG, stranded, 5,000 volts.

THRESHOLD LIGHTS.—The threshold lights are a part of the approach light system. Four sets of light systems are used in the threshold light configuration. These lights are as follows: inboard threshold lights, winged-out threshold lights, prethreshold wing bars, and a terminating bar. These four sets of lights are installed on both ends of the runway and are used to mark the beginning of the runway.

Inboard Threshold Lights.—Inboard threshold lights are installed in the area at the end of the runway between the two runway edge light lines. This line of lights will be at a right angle to the runway center line. They arc as close to the full-strength paving as possible but not more than 10 feet from it. The lights are spaced 10 feet apart. Their color is aviation green. (See fig. 6-35.)

Winged-Out Threshold Lights.—The winged-out threshold light bar is on the same light line as the inboard lights. These lights extend out from the end of each side of the inboard light bar. Each bar is 40 feet long and has nine lights spaced 5 feet apart. The first light location is at the intersection of the runway edge light line and the threshold light line. The color of these lights is also aviation green. (See fig. 6-35.)

Prethreshold Wing Bars.—A prethreshold wing bar is located on each side of the extended runway center line 100 feet out from the threshold. The innermost light of the bar is 75 feet from the center line. Each bar (14 feet long) has five aviation red lights spaced 3 l/2 feet apart. (See fig. 6-35.)

Terminating Bar.—The terminating bar is located in the overrun area. The light bar is at a right angle to the runway center line and 200 feet out from the runway threshold (100 feet out from the prethreshold lights). There are 11 aviation red lights in the bar. The bar is 50 feet long and is arranged so that one half of the bar is on each side of the center line. The lights are arranged in three groups: five lights spaced 3 l/2 feet apart on a 14-foot bar in the middle and, on each side, one I O-foot bar of three lights spaced 5 feet apart. (See fig. 6-35.)

Obstruction Lights

Obstruction lighting is a system of red lights used to show the height and width of natural or man-made objects that are hazardous to air flight. These lights are for the safety of aircraft in flight. The lights must be seen from all directions and are aviation red in color.

The obstruction lights are turned on during all hours of darkness and during periods of restricted visibility. They are placed on all objects with an overall height of more than 150 feet above ground or water within the airspace.

At least two lights (or one light fixture with two lamps) are located at the top of the obstruction. When the top of an obstruction is more than 150 feet above the level of the surrounding ground, an intermediate light. or lights, is provided for each 150 feet. These lights are equally spaced from the top to the bottom.

Where obstructions cover an extensive horizontal plane, the top lights will be put on the point or edge of the obstruction highest in relation to the obstruction-marking surface. The lights should not be spaced more than 150 feet apart. This spacing indicates the general extent of the obstruction. Double lights are used at the horizontal limits of the obstruction, and single lights are used for intermediate lights. If two or more edges are of the same height. the edge nearest the airfield is lit.

On overhead wires, obstruction lights are placed at intervals not exceeding 150 feet and at a level not below that of the highest wire at each light location.

Obstruction lighting systems are served by, either a series or a multiple circuit. The type of circuit used depends on the location of the obstruction and the type of lighting equipment installed. The six most common types of circuits that may be used for the obstruction lights are as follows:

1. Low-voltage multiple service from the vault when the length of the circuit is less than 800 feet
2. Series circuit when the load is less than 4 kilowatts (kW) from a taxiway type of regulator in the vault
3. Twenty-four hundred-volt service from the vault to a distribution transformer to serve a multiple circuit
4. Twenty-four hundred-volt service from the vault to a CCR that serves a series circuit
5. Control circuit from the vault that operates any of the previously listed circuits by means of a relay
6. Time clock or a photocell with a series or multiple circuit for the lights

Obstruction lights on objects that are more than 150 feet above ground or water must be on all the time or controlled by a photocell.

Beacon Lights

The landing facility location is provided by the aeronautical beacon. The beacon is a high candlepower flashing light visible throughout 360 degrees. It provides the pilot a visual signal to locate and identify airfields during night operations or during periods of restricted visibility, day or night.

There are three functional types of beacons that we will discuss: the airport beacon; the identification, or code beacon; and the hazard, or obstruction beacon.

The airport beacon is normally located within 5,000 feet of the airfield. The rotatable unit will display alternate double-peaked white flashes and a single green flash to identify the airfield as a military facility. The size of the unit is about 24 inches; a rigid drum duplex type with a clear double-flasher spread-light lens on one end and a plain green lens on the other. There is an automatic built-in lamp change in case of lamp burnout. An illustration of a typical airport beacon is shown in figure 6-38. Beacon lights may be manually controlled from the tower or from the lighting vault. If the facility is not operated on a 24-hour basis, an automatic control is possible with a photoelectric control that turns the unit ON or OFF automatically.

The identification beacon, or code beacon, identifies an airfield where the airport beacon is more than 5,000 feet away from the airfield or where two or more airfields are close enough to use the same airport beacon. This nonrotatable unit can be seen from all directions and is equipped with a flasher switch operating at 40 flashes per minute with a range adjustment. The beacon has white lenses with green filters and is manually controlled from the tower but may be controlled automatically.

The third beacon, the hazard, or obstruction beacon, furnishes visual identification of natural features or structures that are 150 feet above airfield elevation for on-station or off-station hazards; that is, tanks, towers, stacks, and so forth. The beacon uses white lenses with red filters and is manually controlled from the tower. When automatic controls are desirable, a photoelectric control system may be used. Since the beacon does not rotate, a flashing system is used-flashing 26 times per minute. The beacon lamps and motor require 120 volts for operation. Most of the time, this unit is fed by a 120/240-volt or 120/208-volt, three-wire service. You can use a 120-volt, two-wire service, but it is not recommended. When the lighting vault is less than 800 feet away from the beacon, a low-voltage service can be used. When the vault is more than 800 feet away, high voltage (2,400 volts) from the lighting vault is used to supply a distribution transformer at the base ofthe beacon. You also can run a control wire from the vault to the beacon to operate a relay that, in turn, switches on the power from a local source near the beacon. The last method works best when the beacon is at a remote location from the airfield.

Because of the extreme hazard to life, an alternate low-voltage source near the beacon is usually required.

TYPES OF FIXTURES AND LAMPS

To meet different system requirements, you must have different intensities of lighting. Along with these systems, you need different kinds of fixtures to meet

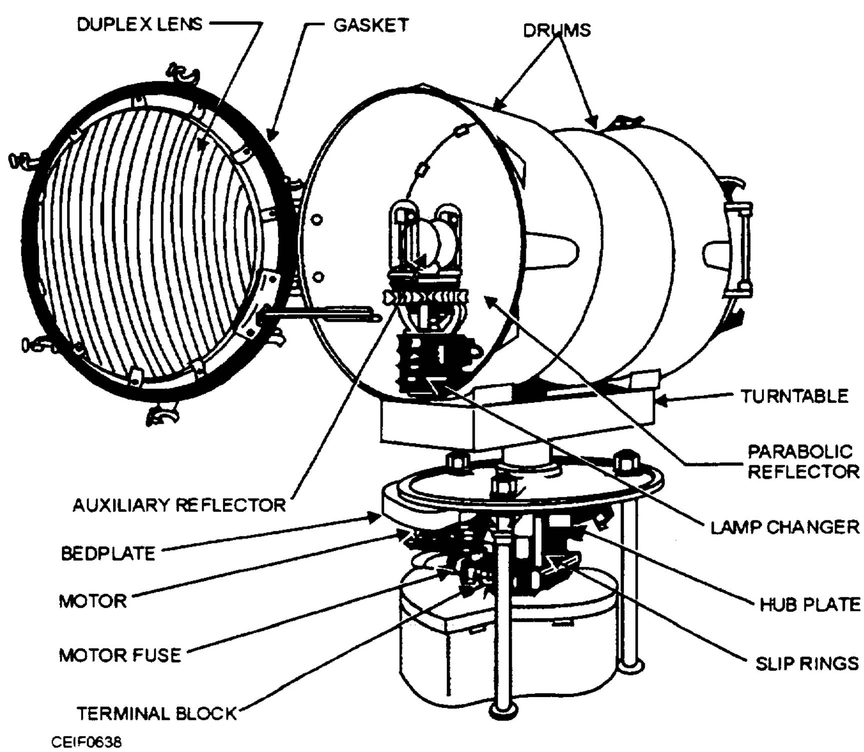


Figure 6-38.—Beacon with one door open and base pan dropped.

the needs of designated locations. In each fixture, a certain type of lamp must be used to give off the right kind of light. A runway light fixture, in a series loop system, requires an isolation transformer (IT). These transformers must be matched to each lamp according to amperage and watts. Figure 6-39 provides you with a pictorial view of the lighting fixtures used in contingency airfield operation; table 6-3 provides the Naval Air System Command part number of each fixture plus the number of fixtures required per given type of field installation.

Several different types of lights are used. The exact type used depends on the system. Not only are there different fixtures for different widths of runways, but there are different intensities. In most cases, high-intensity lighting systems are used for high-speed aircraft. Also, high-intensity lighting systems are required during low-visibility conditions.

CONDENSER DISCHARGE LIGHTING SYSTEM

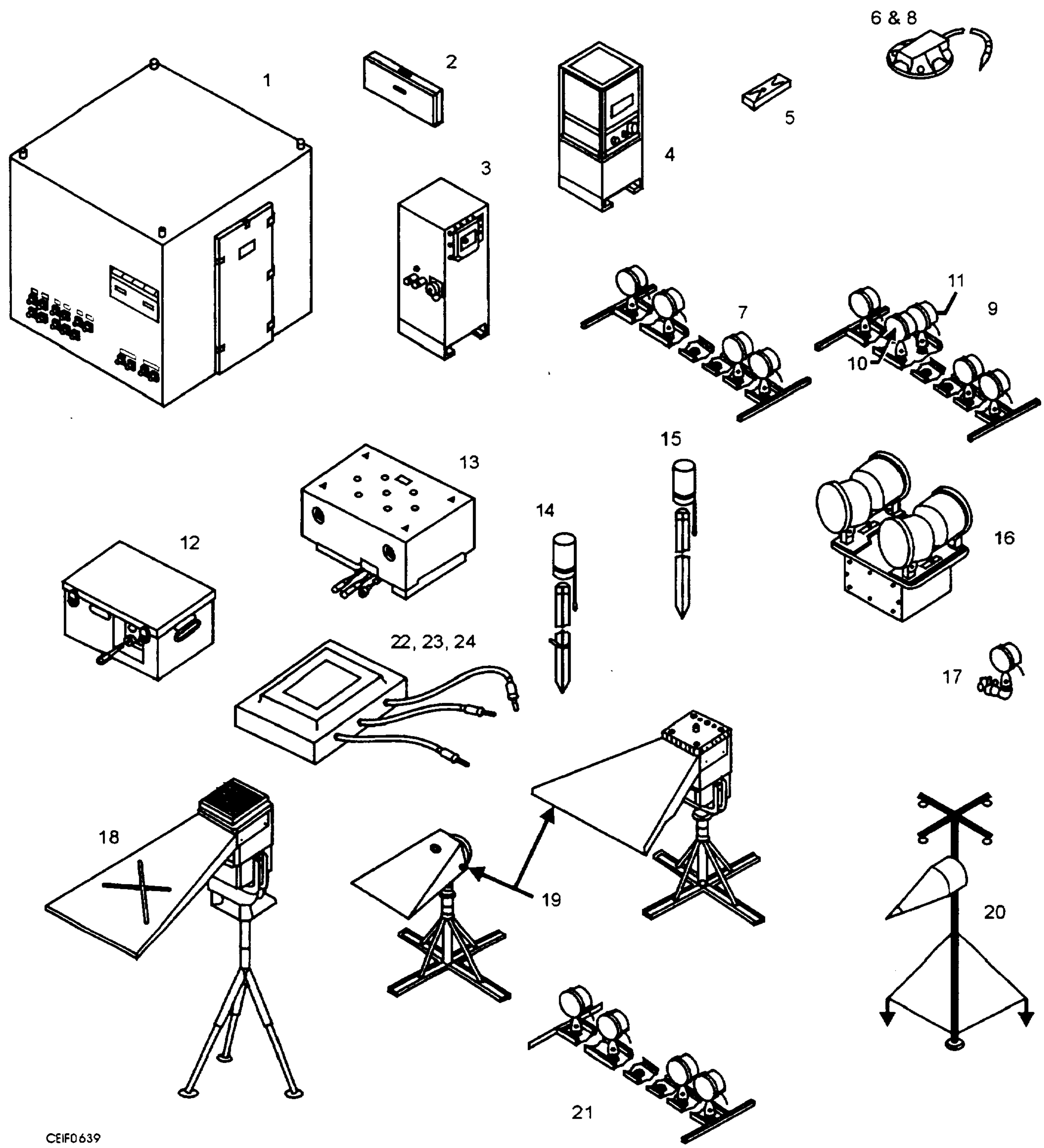
The condenser discharge lights are added to make the approach system complete. Because the lamps flash on and off to give a stroboscopic effect, the term **strobe** is used for these lights. From here on out, the term strobe will be used when referring to condenser discharge lights.

The transformer and the master sequence timer cabinet are located in a small vault or pad near the center ofthe approach system. The vault or pad should be secured so neither animals nor unauthorized personnel can enter..

Table 6-3.—Airfield Lighting Equipment Required.

Component	NAEC Part Number	Quantity Per Field			
		VTOL 900'	VSTOL 1,800'	EAF 5,200'	SEL F 8,00 0'
Approach Light Assembly	505954-1	10	20	20	20
Center-line Light Assembly	613593-1	17	34	86	51
Circling Guidance Light Assembly	508233-1	-	8	16	16
Electrical Distribution Vault	615220-1	1	1	1	1
Floodlight Assembly 500W	615902	26	54	125	125
Floodlight Assembly 200W	615506-1 or 616324-1	12	12	24	12
Obstruction Light Assembly	505956-1	10	10	20	20
Regulator Constant Current 4kW	*616040-1	1	2	2	4
Regulator Constant Current 15kW	*614384-1	6	7	11	11
Remote Control Assembly	614896-1	1	1	1	1
Rotating Beacon Assembly	609990-1	-	1	1	1
Rotating Light Assembly	505954-2	4	4	-	-
Runway Light Assembly	615911-1	18	32	64	66
Status Light Assembly	409823-1	-	2	2	2
	409823-2	-	2	2	2
Strobe Light Assembly	506208-1	10	10	10	10
Strobe Power Supply	610361-1	10	10	10	10
Strobe Timer Assembly	610036-1	2	2	2	2
Taxiway Light Assembly	615910-1	37	92	122	228
Threshold Light Assembly	505954-3	8	8	-	-
	505954-4	-	-	4	4
Wind Cone Assembly	506054-1	1	2	2	2
**Lamp Holder	413021-1	10	-	-	-
**Adapter Bracket	423041-1	10	-	-	-
**Lamp	MS24348-5	10	-	-	-

*616040-1 and 614384 replaced with 618650 and 616360. respectively when supply is exhausted.
**Components of extended line-up light.



1. Electrical distribution vault
2. Remote control assembly
3. 4-kW constant current regulator
4. 15-kW constant current regulator
5. Center-line sight
6. Runway light
7. Threshold light
8. Taxiway light
9. Approach light
10. Strobe light
11. Extended line-up light
12. Strobe timer
13. Strobe power supply
14. Obstruction light
15. Circling guidance light
16. Rotating beacon light
17. Status light
18. 500-W floodlight
19. 200-W floodlight
20. Wind cone assembly
21. Rotation light
22. Transformer - runway and approach
23. Transformer - taxiway
24. Transformer - work area

Figure 6-39.—Airfield lighting components.

The major components of the condenser discharge lighting system are the elevated and semiflush strobe light units, the master sequence timer cabinet (containing the local/remote control unit, the monitor and control chassis, and the master sequence timer), and the tower control unit.

Strobe Light System

The strobe lights are installed on each center-line light bar starting 300 feet from the runway threshold and extending outward for the length of the system. The strobe light will be located on the center-line light bar, midway between the center light and the next light on either the left or right side. They can be placed in front of the light bar but not more than 10 feet. No matter where they are placed, they must be in the same position on each light bar throughout the entire approach system.

In the overrun area, the strobe lights are installed as flush lights. Starting with the 1,000-foot bar (decision bar) and going out, an elevated type of strobe light is used. An elevated approach light bar looks like the one shown in figure 6-40.

The strobe lights are controlled from the remote control panel. They can be turned on and off independently or so triggered that they come on when the approach light switch is in either the third, fourth, or fifth brightness position. The brightness of the strobe lights cannot be controlled.

The strobe lights put out a high beam of light that peaks at 30 million candlepower. DO NOT LOOK INTO THE BEAM OF LIGHT WHEN YOU ARE NEAR ONE OF THE LAMPS OR YOUR EYES COULD BE DAMAGED. The system we discuss here is one of several different types manufactured. The operation is the same no matter who manufactures them. Your knowledge of one will give you an understanding of the others.

Strobe lights are either flush mounted or elevated. The operation of the flush light is exactly the same as that of the elevated light unit. The main difference between the units is the way in which the components are arranged. We will be discussing the condenser discharge strobe light unit (figure 6-41); the numbered areas in parenthesis will refer to the numbered items in the figure.

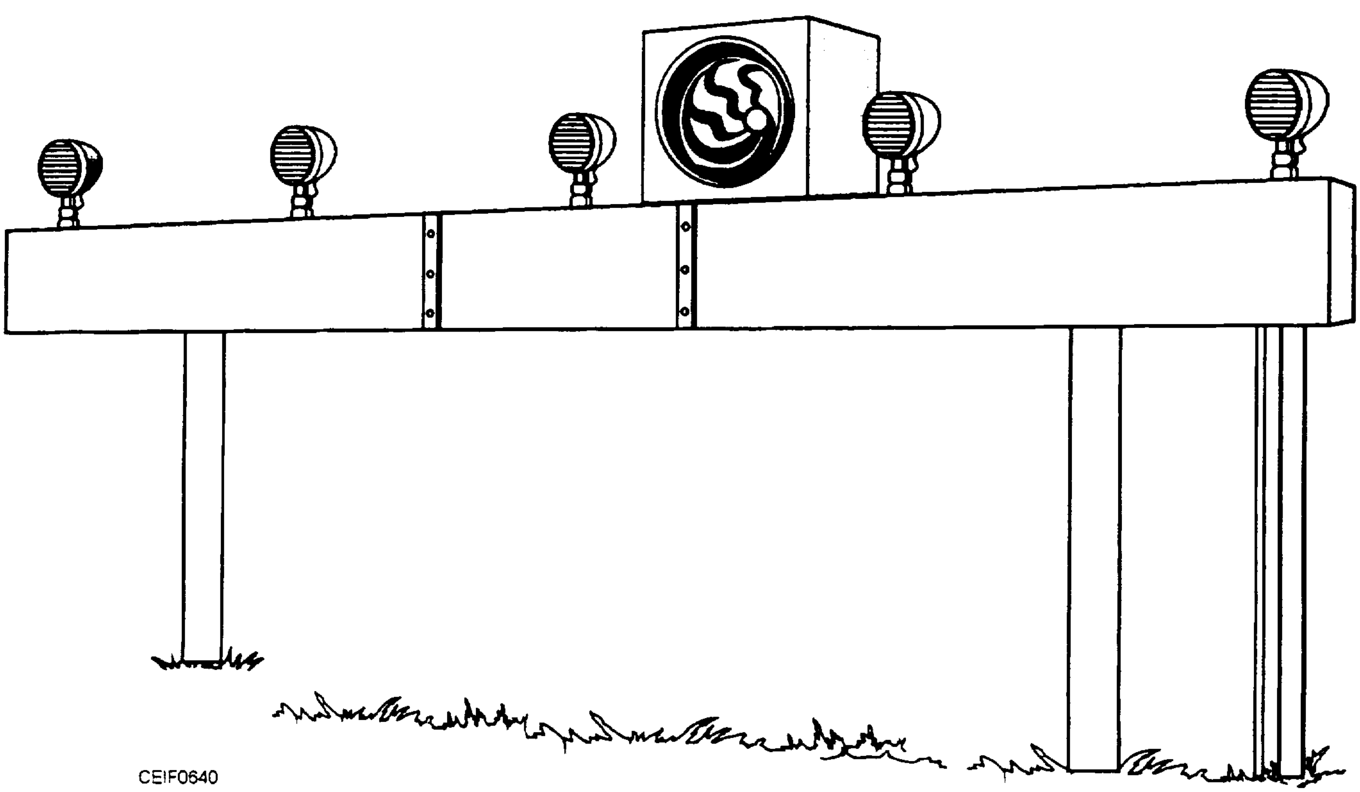


Figure 6-40.—Elevated approach light bar.

Each strobe light has four inputs from the rest of the system: (1) 240 volts ac, (2) ground, (3) 120 volts ac timing pulses at the rate of two per second, and (4) a dc voltage connection to the monitor system. These inputs are plugged into a cable through a four-pin connector (No. 10). The unit steps up the 240-volt ac input voltage to 1,460 volts ac with a transformer (No. 15) and passes this voltage through a full-wave rectifier circuit of vacuum tubes (No. 13). The resultant 2,000 volts dc is applied to the electrodes of a flashtube and across the flash capacitor (No. 4).

The xenon-filled flashtube will fire only when ionization is initiated by a trigger pulse of about 5,000 volts applied to its third electrode. This pulse is supplied by a trigger coil. At the same time that the flash capacitor is storing its charge, the trigger capacitor is also being charged by the primary of the trigger coil, which is an autotransformer, and cuts the bleeder resistors in series out of the circuit. When the l20-volt ac timing signal arrives, it is applied to the coil of the trigger relay (No. 9), thus closing the relay contacts, allowing the trigger capacitor to discharge through the primary ofthe trigger coil. That generates the necessary trigger pulse in the secondary of the trigger coil, the flashtube fires, and the flash capacitor discharges across the flashtube electrodes. The flash capacitor discharges down to the deionization potential of the flashtube, at which point the tube becomes a nonconductor. The light-producing arc ceases, and the charge cycle begins again.

The charge stored in the flash capacitor is a potential safety hazard. To make sure that the capacitor is discharged when the light unit is shut off, provide a discharge circuit by a series of bleeder relays. The bleeder relay (No. 5) closes this discharge circuit when the power to the transformer is turned off.

The current that charges the flash capacitor creates a pulse voltage in a surge resistor twice each second. A part of this voltage is applied to a silicon rectifier through a tap-off of the surge resistor. The rectified voltage is then filtered and applied to the monitor relay. The value of this voltage is sufficient to keep the monitor relay energized when the unit is flashing normally. When the unit stops operating because of a component failure in the unit, the absence of the pulse voltage at the surge resistor will allow the contacts of the monitor relay to close. This action completes a circuit from the monitor connection through a monitor resistor of 22 kilohms to ground. The monitor and control chassis react to the ground by warning the operator.

Master Sequence Timer Cabinet

The master sequence timer cabinet has all of the controls for the strobe light system except the tower control unit. The cabinet is supplied from a 240-volt, phase-to-ground circuit. Our discussion of how the system operates is keyed to the numbered items in figure 6-42.

LOCAL/REMOTE CONTROL UNIT.—The local/remote control unit (No. 1) gives you a way to turn the system on locally or give control to the tower. In the center of this unit is a control knob with three positions: REMOTE/OFF/LOCAL-ON. There are two red indicator lights above the control knob and two green lights below it. When the control knob is in the LOCAL-ON position, the system is turned on, and red lights will glow to indicate that the system is on LOCAL CONTROL. The green monitor lights should burn unless there is a fault in the system; in which case, they will go out. When the control knob is placed in the REMOTE position, the system can be turned on and off at the tower control unit. The red indicator lights will go out, but the monitor lights will continue to work as before. You should remember that the tower has no control except when the switch is in REMOTE.

MONITOR AND CONTROL CHASSIS.—The monitor and control chassis has several functions. They are as follows:

1. It de-energizes the monitor lights in both control units when a set number of lights stop working.

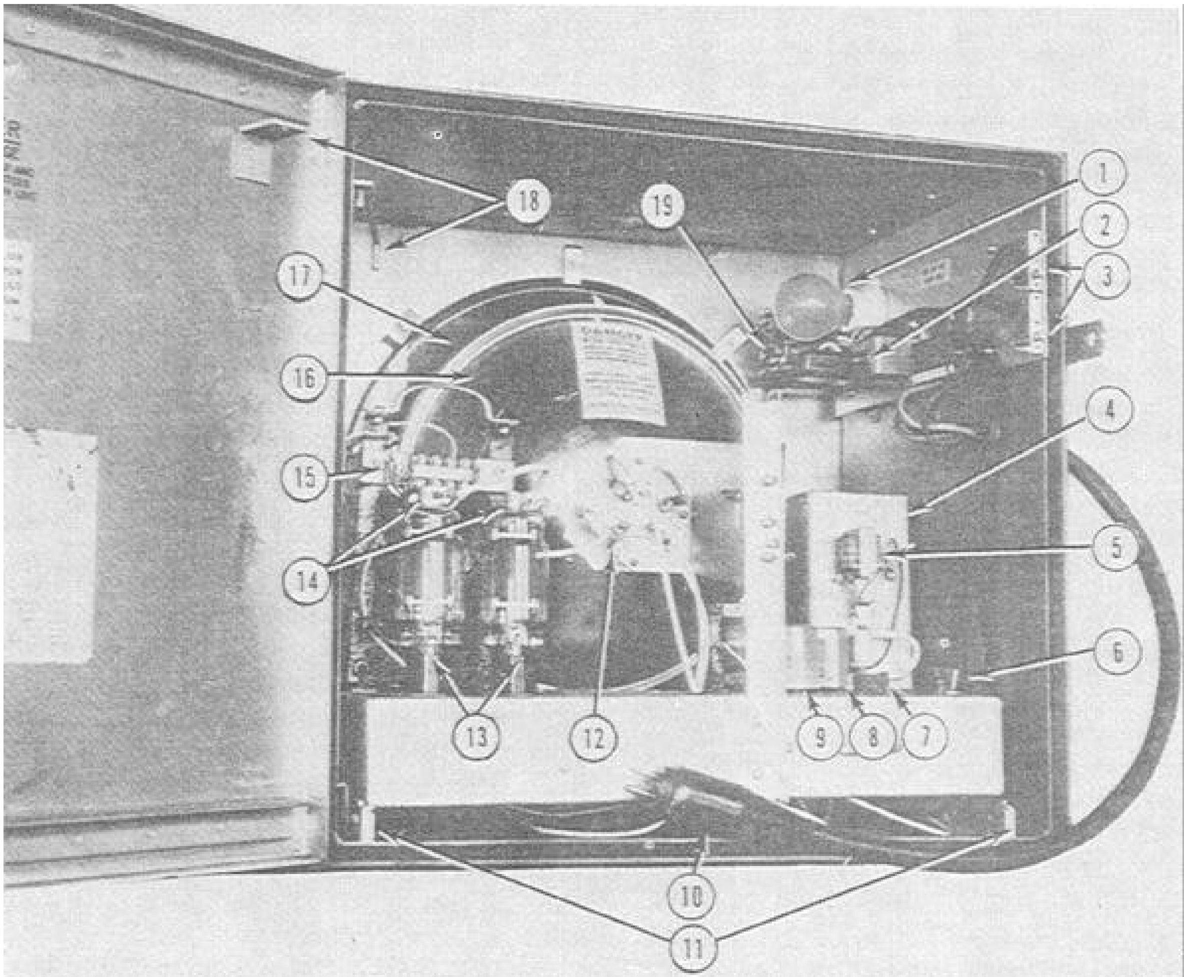
2. It has a step-down transformer to supply the voltages needed for control and indication.

3. It has a diode rectifier that supplies direct current for relay operation.

4. It has the fuses that protect the master sequence timer, the indicator circuits, and other components.

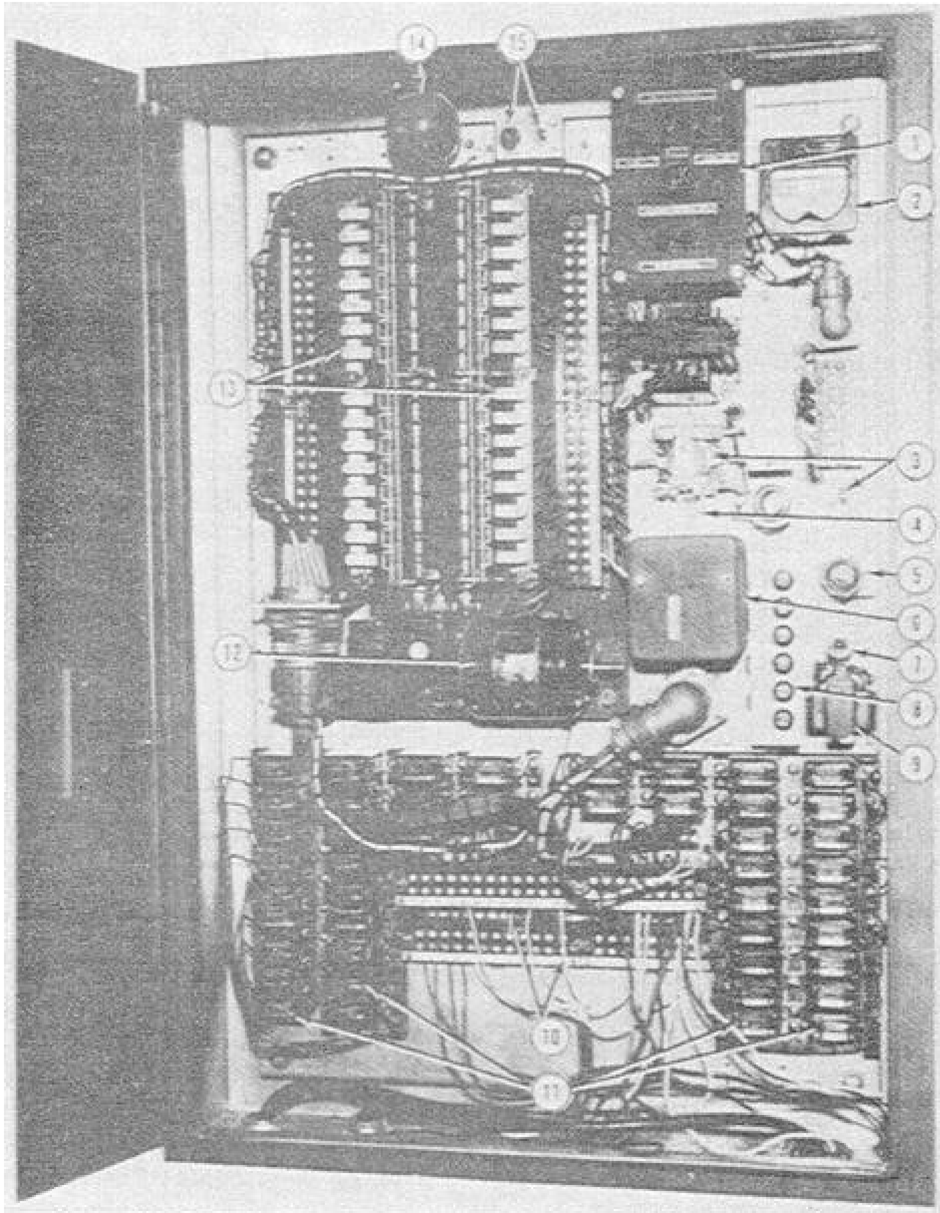
The main power transformer in the monitor and control chassis is energized all the time from a local 240-volt ac supply. The secondary voltage from this transformer energizes the indicator lamp transformer and the transformer of the dc circuit. The indicator lamp transformer supplies 12 volts ac to the indicator lights in the local/remote control unit. The transformer for the dc power will supply 95 volts ac to a bridge rectifier that supplies 120 volts dc to the dc monitor circuit.

As long as the master control switch is on, power is fed to the tower csontrol unit no matter what position the local/remote control unit switch is in. When the



1. Cabinet light (240 V)
2. Light switch and fuse
3. Safety interlock switches
4. Flash capacitor
5. Capacitor bleeder relay
6. Fuse and switch, 240-volt power
7. Connector receptacle
8. Monitor relay
9. Trigger relay
10. Four-pin connector
11. Tracks
12. Flashtube socket
13. Rectifier tubes
14. Plate caps
15. Transformer
16. Reflector
17. Glass
18. Door stop and bracket
19. Lightning arresters

Figure 6-41.—Condenser discharge strobe light unit.



1. Local/remote control
2. Elapsed time meter
3. Main relay and switch
4. Sensitivity rheostat
5. Sensitivity selector switch
6. DC power supply
7. DC regulator tube
8. Fuses
9. 12-volt transformer
10. Terminal blocks
11. Lightning
12. Timer motor
13. Timer switches
14. Cabinet light (240 volts)
15. Fuse and light switch

Figure 6-42.—Master sequence timer and controls.

flasher control switch in the vault control unit is closed, the dc power interlock relay closes and energizes the monitor lights in the tower control unit. The unit responds in the same way as if the system were in full operation and working well. For this reason. the tower personnel must be notified when the switch in the local/remote control unit is in the OFF position. When the flasher control switch on the local/remote control unit is in the OFF or LOCAL-ON position, the red indicator lights tell you that the tower control unit is not in full operation.

There is a monitor-sensing relay to monitor the operation of the strobe lights. When all the light units are working correctly, there will not be enough current through the coil ofthe monitor-sensing relay to actuate the relay. A variable adjustable resistor can be adjusted so that there will be 7,333 ohms of resistance between the monitor-sensing relay and ground. A resistance of 7,333 ohms equals three 22-kilohm resistors in series. The monitoring circuit in each light unit has a 22-kilohm resistor. So, if you take the three 22-kilohm resistors out of the monitor control unit, the monitor-sensing relay actuates when at least three light units have ceased to work and their monitoring circuits are grounded, as described earlier.

The sensitivity selector switch lets you reduce the number of malfunctioning lights needed to actuate the monitor-sensing relay by increasing the current flowing through its coil. There are three 22-kilohm resistors in the monitor control unit. Each of these three resistors simulates the effect of a grounded monitor connection to one of the lights.

If the monitor-sensing relay is tripped, the monitor lights on the local/remote control unit will go out. At the same time. the monitor lights in the tower control unit go out and a buzzer sounds.

The adjustment for the sensitivity of the monitor system is made at the monitor and control chassis in the master sequence timer cabinet.

With all of the strobe lights operating and the sensitivity selector switch in the No. 1 UNIT position, the green monitor lamps should be on. If you turn the strobe light units on and the monitor lights do not come on, you need to adjust the sensitivity of the variable resistor (sensitivity rheostat). You need a small screwdriver to fit the slot in the rheostat shaft (No. 4). Turn the shaft clockwise as far as it will go (about half a turn). The green lamps should now be lit. Now, turn the rheostat counterclockwise slowly until the green lamps go out. Then turn the rheostat back clockwise slowly and stop as soon as the green lamps light. Check this setting by slipping a piece of paper between the contacts of one of the timer switches. The monitor lamps should go out. Remove the paper and turn the control switch to OFF for a few seconds and then to ON. The green lamps should now stay lit. Repeat this procedure for different lamps and shift the rheostat slightly if you need to until you find a setting that will operate for any of the approach lights.

Change the sensitivity selector switch to the No. 2 UNIT position and repeat the procedure while blocking two ofthe switches with pieces of paper. That is like having two strobe light units out and should have the same results as before. Restore the monitor lights the same as before. Repeat the procedure with the sensitivity switch in the No. 3 UNIT position while you block three of the timer switches. Now, check the operation ofthe monitor circuit with number 1, 2, and 3 strobe lights out.

When you find the correct setting of the rheostat, no further adjustments should be needed. When your base requires the selector switch to be on the No. 1 UNIT position, then, in proper operation, if one strobe light fails, the alarm is silenced by just moving the selector switch to the No. 2 UNIT position. The switch is left in this position until the bad strobe light is fixed. At that time, the selector is returned to the No. 1 UNIT position.

MASTER SEQUENCE TIMER.—The master sequence timer controls the order and rate of the triggering impulses to the light units. The timer has two camshafts driven by a motor (No. 12) through a reduction gear. The cams actuate 30 contacts (No. 13)—one for each light unit—staggered on the shafts so that the contacts are closed in rapid succession as the shafts turn. Note that although there are 30 contacts, only 28 are used. Each ofthe 28 contacts is electrically connected to one of the light units. Thus, when the motor is energized, the contacts are momentarily closed in a predetermined sequence twice each second. That provides a series of 120-volt ac pulses to the trigger relays in the lights. These pulses are known as the timing circuit. Power for the 120-volt motor and the 120-volt timing pulses comes from the monitor and control chassis. An elapsed time meter (No. 2) is mounted next to the timer to show the total time the equipment has been in use; thus it serves as a guide for maintenance. Forty-five lightning arresters (No. 11) are installed in the lower part of the cabinet to protect the equipment from voltage surges on any ofthe lines.

Tower Control Unit

The control switch on the tower control unit works only when the local/remote control unit in the timer cabinet is in the REMOTE position. The audible and visible monitoring alarms, however, are operable whenever the system is in use, even if the local/remote unit is at the LOCAL-ON position. Adjustments are provided on the panel for regulating the brightness of the two green monitor lights and the loudness of the buzzer. A push-button switch is used to test the operation of the buzzer.

MAINTENANCE OF AIRFIELD LIGHTING SYSTEMS

Regardless of the design of an airfield system, maintenance is highly recommended to ensure the operational dependency of the field. Routine scheduled downtime is much better than unscheduled downtime in the midst of an operation. Simple visual inspection plus periodic resistance readings of circuit devices, components, and cables reveal probable trouble areas.

Do not get caught in the “jury-rigged trap.” This tendency to patch, bypass, piece together, or otherwise rig a system to work “just for a little while” can be as dangerous as a coiled rattlesnake. That “temporary fix” is just sitting there waiting to catch some uninformed individual sent **out** to work on the system. This section covers routine maintenance for airfield lighting and underground systems, troubleshooting cable systems, and cable splicing and repair.

ROUTINE MAINTENANCE

Routine maintenance includes, but is not limited to, cleaning, adjusting, lubricating, painting, and treating for corrosion. Components and connections must be checked for condition and security. The insulation of the conductors should be checked for good condition and burns, scrapes, breaks, cracks, or evidence of overheating.

Visual Inspection

During your visual inspection of an airfield lighting wiring system, you should check the constant-current regulator (CCR) for chipped or cracked porcelain bushings, correct connections, proper fuses and switches, and relays for freedom of movement. Only relay panel covers should be removed. It is not necessary to open the main regulator tank. All covers that are removed should be cleaned and then reinstalled tightly. Cable and isolation transformer connectors require close visual inspections for cuts, bruises, or other mishandling; these conditions could cause premature failure to the system. The mating surfaces of these molded rubber connectors must be clean and dry when they are plugged together. Either dirt or moisture prevents the mating surfaces from making complete surface contact and **causes a** failure at the connector. When connectors are plugged together, trapped air can cause them to disengage partially. Wait a few seconds and push them together again. Apply two or three turns of tape to hold them in place. When the connectors are clean, dry, and taped properly, the connection is equal or superior to a high-voltage splice.

Check light fixture connections for tightness. Look for cable bends that are too sharp; sharp bends can cause insulation breakdown or connector failure.

Operational Check

Once all components of the system have been visually inspected for damage and the cable system has been checked with a megger and hi-pot, make an operational check ofthe entire airfield lighting system.

1. Working from the control tower with an observer in the vault, operate each switch of the airport and taxiway panel, so that each position is reached at least twice. You must have radio or telephone communication with the observer in the vault during this operation. The observer in the vault determines that each switch properly controls its corresponding circuit.

2. Repeat this operation from the vault (alternate control panel) in the same manner, assuring that each switch position is reached twice.

3. Now, repeat the test by using the local control switches on the regulator.

4. Operate each lighting circuit at maximum brightness for 6 continuous hours. Make a visual inspection of all lights, both at the beginning and at the end of this test to assure that the proper number of lights are operating at full brightness. Measure lamp terminal voltage on at least one lamp in each multiple circuit to assure that this voltage is within ±5 of the rated lamp voltage. Dimming of some or all of the lights in a circuit indicates grounded cables.

Condenser Discharge Light System

Periodic maintenance of this system is fairly simple. **Remember,** however, that **high voltages exist** in the components of the system and you must be extra careful. One such area is the **flash capacitor.** This capacitor may contain as much as 2,000 volts. **Anyone working on the light fixture should make sure that this capacitor is discharged before working on the light unit.** The capacitor should bleed down through its resistor network in 5 seconds; however. the capacitor should be shorted out before any work is done inside the unit. In a flush unit short between terminals 7 and 10 ofthe terminal board with a shorting stick. In the elevated light, short the two contacts on the left side of the flashtube socket. **That must be done before any work is done inside the light unit, such as changing a flashtube or cleaning the reflector.**

WARNING

Anyone working on a condenser discharge light system must make sure that the capacitor is discharged before working on the light unit.

Since these are sealed units, cleaning the reflectors rarely should be required. When such cleaning is required, be sure to use a nonabrasive cleaner. The lenses in both the ‘elevated and flush units should be cleaned periodically, depending on the local conditions.

Inspect the timer contacts to see that they are clean and making good contact. If not, the stationary timer contacts can be adjusted. The timer gears ofthe master sequence timer require periodic lubrication. Match the grease to the ambient temperatures expected in your particular area. **NEVER use a graphite-based grease, as graphite is electrically conductive.**Check to see that both pairs of green indicator lights will light. When only one lamp is lit on either unit, the other bulb has burned out. To replace one of these bulbs, remove the front panel, pull off the colored lens, push out the old bulb, and insert the new bulb from the front of the panel. Replace the lens and panel.

Underground Distribution System

Normally speaking, underground systems that are properly installed require little maintenance of the routine type. Since both the equipment and the cable are well protected from man and the elements, the system normally is not subject to the same problems that overhead systems experience.

In some areas, groundwater or dampness may create some problems for underground systems by increasing rust or corrosion. Racks and splice boxes may require more painting and other rust or corrosion maintenance. Look especially for rusted nuts on boxes and rack hangers. They should be cleaned and painted. The manholes and vaults should be cleaned. These areas should not be used for storage or should trash be allowed to collect in them.

Check the manhole walls for evidence of cracks, breaks, or other evidence of water seepage or leakage. Check empty ducts for plugs and evidence of water seepage.

You will find manholes with enough water in them to hamper or prohibit work operations. In such cases, bail the water out with a bucket and rope or pump it out with a manhole pump. Sometimes sump holes are built into the floor of manholes, and these provide places to bail from or to pump from the lowest places in the manhole. When water runs into a manhole from unoccupied ducts, hard rubber plugs are provided to stop or slow the water. When the manhole pump is used, place it in a position so the flow of water will be away from the manhole. That would be on the downhill side. Place the pump at least 10 feet from the manhole opening. The pump has a hose to be inserted in the manhole and an outlet hose to carry the water away from the manhole. Check cables for proper racking, making sure that they are trained in the proper direction and positioned so an ample cable radius is left for bends and expansion/contraction. This radius is basically 5 to 12 times the cable diameter, depending on the sheath type and the number of conductors. Make sure that 6 inches of straight cable exists for racking on each side of the splice. Check splices for evidence of leakage or tracking. Look for scrapes, burns, cracks, corrosion, or any other evidence of cable insulation deterioration. See that all cables are properly tagged for identification.

Check potheads and terminations that are attached to risers for leakage, tracking, and evidence of overheating or an overvoltage. Also, check the security of the mounting of the pothead and conduit.

TROUBLESHOOTING CIRCUITS

Troubleshooting of cable systems is much the same as any other type of electrical troubleshooting. You need a thorough knowledge of the system as well as the ability to analyze problems. A review of the history ofthe system provides clues to present or future troubles. Simply using your eyes and head is sometimes the most effective method of locating the trouble. A knowledge of test equipment, an ability to read drawings or schematics, and an understanding of electricity are the key factors in locating electrical troubles.

Types of Trouble

The same basic types of trouble can occur in the airfield lighting cable system whether that system is in series or in multiple; however, the results of these circuit troubles can cause dramatic differences; for instance, a short circuit across the terminals of a distribution transformer supplying a multiple system is a dangerous overload; and the same short circuit across the output terminals of a CCR and series transformer is a no-load condition. An open in the output circuit of a CCR, on the other hand, creates a dangerous overload. Burned-out lamps in the secondary of a series circuit will not damage the transformer, but the secondary voltage will rise above normal and distort the wave shape ofthe primary current. When enough lamps bum out. the primary current may rise high enough to shorten lamp life and possibly damage the regulator. These critical factors should tell you why you need to know the circuit.

In the discussion above, all types of electrical trouble were mentioned; for example, opens, shorts, grounds, and improper power.

OPENS.—An open circuit is an incomplete circuit. Somewhere the circuit has a break; therefore, there is not a complete path for current flow throughout the circuit. Because there is no current flow, the circuit cannot operate. In analyzing circuit trouble, if the lights are not burning, the motor is not running, and so forth, you need to look for a break in the circuit. Usually this break will be at the unit(s) of resistance (burned-out lamp, broken resistor, motor burned out), but sometimes the break will happen in the cable. When the cable breaks, this break is most likely to happen at a splice or connection. Other cable breaks may be caused by digging operations being done in the wrong place. That occurs when base maps are not kept up to date and when unauthorized digging operations take place. It is an excellent reason for installing and maintaining direct burial cable markers.

Improper installation of cables can cause them to fail. Cables may be damaged by kinking, bruised by rocks, crushed by wheels, or cut by shovels when proper care is not exercised during handling and installation. While the damage at the time it occurs may not be great enough to take the cable out of service, it may be the starting point for a cable failure at a later date. This failure may be either in the form of a broken cable (open), cross type of short (two cables touching), or a short to ground (cable in contact with earth ground). Any of these troubles can render the circuit inoperative. The indication of the type of trouble that you have in the circuit and the point in the circuit where this indication appears should assist you in locating and repairing the circuit.

With an open circuit, that portion of the lighting system being supplied by the effected cable will not operate. A string of lamps that do not light, then, would indicate an open cable.

SHORTS.—If lamps are lit when they are not supposed to be or if a circuit is affected by another circuit, you most likely have a cross type of short between the two circuits. The logical point to start looking for this trouble is where the two cables cross orss where they are close to each other.

GROUNDS.—When a string of lights bums dim or when fuses blow on a circuit, you have a short to ground. The insulation on the supply cable is damaged. This defect lets current pass directly from the conductor to the earth and prevents the lamps from receiving enough power to operate correctly; that is, some of the resistance of the circuit is being bypassed. The amount of resistance being bypassed in the circuit governs the effect of the short to ground. If enough resistance is removed (bypassed), then the current rises to a point that is sufficient to blow the fuses and thus disconnect the circuit.

IMPROPER POWER.—Improper power can result when regulators or distribution transformers are not connected properly. If the incorrect input voltage is connected or if the regulator has been purposely connected for an unusual load requirement, improper power can be applied to the system and serious damage may result.

Underground Lighting Problems

The care and craftsmanship of the original installation will, to a large extent, determine the life of the system. Still, no system lasts forever. Even the best installation and the most conscientious inspection and maintenance program cannot prevent the aging and gradual breakdown of a system. In almost all cases when an underground cable breaks down, it goes to ground. Where more than one conductor is enclosed in one sheath, the insulation within the sheath may deteriorate so that a cross type of short occurs. This contact almost always creates enough heat and pressure to rupture the sheath and put the conductors in contact with ground.

Moisture is one of the most common causes of an underground system breakdown. Impurities in the water help set up corrosion cells, break down neoprene, and rot rubber. Only a trace of moisture, when superheated by the electrical power of the circuit and converted to steam, can cause an explosion that will rip the cable to shreds. Groundwater contains enough minerals to provide an excellent conductor to all other parts of the system. Some underground cables are bonded together. The usual way to find out that an underground power cable has a problem is to check when the circuit opens.

In ducted systems, the maximum runs between manholes are 500 feet. The normal method of repair is to replace the cable. In direct burial cable systems, the cable runs may be quite long, and it would be impractical to replace the entire run. In this case, cable fault locators are used to locate the fault. Before starting to work, make sure that all power is off on the circuits in the trench before you start digging or repairing the cable.

This chapter does not discuss detailed circuit troubleshooting because each system is different. When you troubleshoot complex problems that involve airfield lighting, you should refer to the following publications: *Definitive Designs for Naval Shore Facilities,* NAVFAC P-272; *General Requirements for Shorebased Airfield Marking and Lighting,* NAVAIR 51-5OAAA-2; and *Lighting and Marking Systems for Expeditionary Airfields.* NAVAIR 51-4OABA-7. Problems, such as improper power connections, component connections, safety grounding, cable splices, cable terminations, and cable installations, are discussed in detail in these publications.